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MONTHLY WEATHER REVIEW

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APRIL 1937

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ON THE RELATION BETWEEN RAINFALL AND STREAM FLOW—III

By RICHMOND T. ZOCH

[Weather Bureau, Washington, D. C., April 1937]

PART I

This article of the series deals with the evaporation which takes place after a rain stops, and its effect on stream flow.

Throughout, as in the first two papers, the rate of rainfall, the condition of the soil, and the velocity of the water are considered to be constant.

In the first section of Part II, equations are given which show the effect of evaporation on run-off. (As previously explained, for sufficiently small drainage areas the volume of rate of run-off can be regarded as synonymous with the discharge.) In the second section, equations are developed which give the discharge from a rectangle when the effect of evaporation is considered; in this section the rate of evaporation (or evaporativity) is treated as constant. In the third section, equations are developed which give the discharge from a drainage area of any shape, such as discussed in section 4 of the second paper, and where the rate of evaporation (or evaporativity) is any function of time. In the fourth section the diurnal variation of rate of run-off is discussed. In the fifth and last section a few hypothetical hydrographs are computed from which one can judge of the magnitude of the effect of evaporation on the discharge.

A few definitions will here be given and explained. First of all it is essential when speaking of "rainfall" or "run-off" or "evaporation" to keep clearly in mind exactly what is meant. Each of these three terms could be interpreted as representing a *depth* of water. Again each could be interpreted as representing a *volume* of water, by multiplying the *depth* by the area of a parcel of ground. Each of these terms could also be interpreted as representing a *change in depth per unit time;* in this sense, each term represents the first derivative of a *depth* with respect to time. Again each term could be interpreted as representing a *change in volume per unit time,* in this sense the term represents the first derivative of a *volume* with respect to time. Thus all told, four separate and distinct interpretations can be placed on each of the terms "rainfall", "run-off", and "evaporation". It is imperative to distinguish clearly between these meanings; and for this reason the practice of prefixing the words "rate of", "volume of", or "volume of rate of" to the basic word, as was done in the first paper in connection with "rainfall" and "run-off", will be followed here for "evaporation."

The volume of water (not of water vapor) which is evaporated from a given area in a given interval of time is here denoted the *volume of evaporation.* Like volume of rainfall, volume of evaporation will be measured in mile-inches. It should be clearly understood that the volume of evaporation as here defined includes both the water evaporated from the ground, whether directly or through plants, and also the water evaporated from any free water surfaces which the drainage area in question may contain as lakes, ponds, and streams draining the area. Naturally for some studies it is necessary to distinguish between evaporation directly from the ground, evaporation through plants, etc., but it is not believed that these distinctions are necessary to forecast flood crests accurately.

The volume of water which is evaporated per unit time from a given area at any given time is designated the *volume of rate of evaporation.*

The volume of rate of evaporation is volume per unit time and therefore will be measured in mile-inches per hour. Mathematically, the volume of rate of evaporation is the first derivative of volume of evaporation with respect to time.

The volume of water which is evaporated from a given region in a given interval of time per unit area is here called the *evaporation.* Evaporation is volume divided by area, i. e., it is a length, and will be measured in inches. The volume of water which is being evaporated per unit time, from a given region at any given time, per unit area, is the *rate of evaporation.* The rate of evaporation is volume per unit time divided by area, i. e., length per unit time, and will therefore be measured in inches per hour. Mathematically the rate of evaporation is the first derivative of evaporation with respect to time.

It is well known that, other things being equal, the rate of evaporation is greater when there is a strong wind than when there is no wind; likewise, the rate of evaporation is greater when the air is warm than when the air is cold; greater when the sun is shining than when the sky is overcast; and greater when the relative humidity is low than when it is high. Recognizing these facts, consider the following two situations: First, a piece of ground during one year under specified conditions of culture, temperature, wind, etc., shortly after a heavy rain of long duration; and second, the same piece of ground during another year at the *same* specified conditions of culture, temperature, wind and all other pertinent things with this one difference: A long dry spell has been in progress. Clearly, the rate of evaporation will be greater in the first case than in the second. We can therefore say that the rate of evaporation *may* be dependent upon the amount of water remaining with the soil. That the rate of evaporation is not always dependent upon the amount of water remaining with the soil can be made clear by considering a slough. As long as there is water in the slough the rate of evaporation will be solely dependent on the wind, temperature and other weather elements and *not* upon the amount of water in the slough.

Undoubtedly experiments are necessary to determine just when the rate of evaporation becomes dependent upon the amount of water remaining with the soil; but it would seem that when soil is water-logged, as it may be occasionally, the rate of evaporation would not be so dependent.

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To take account of the fact that the rate of evaporation may be dependent upon the amount of water remaining with the soil, it is necessary to introduce two additional terms: The volume of water which would be evaporated from a given region, were an unlimited supply of water available in a given interval of time per unit area is here called the *evaporativity*. The volume of water which would be evaporated per unit time from a given region were an unlimited supply of water available at any given time per unit area is designated the *rate of evaporativity*. Mathematically, the rate of evaporativity is the first derivative of evaporativity with respect to time. Evaporativity is measured in the same units as evaporation; and rate of evaporativity is measured in the same units as rate of evaporation.

The use here of the term evaporativity, as distinguished from the term evaporation, agrees with the recommendations of a committee of the Section of Hydrology of the American Geophysical Union.[1]

The distinction between evaporation and evaporativity can be explained in a different way: By multiplying the depth of rainfall by the area of a drainage area the volume of rainfall can be computed; if the depth of rainfall varies from place to place within the drainage area, the volume of rainfall should be computed by an integration process. In a similar way the volume of discharge on the stream which drains the region can be computed. If the time of beginning and the time of ending of the time interval be so chosen that the amount of water remaining with the soil is the same at the end as at the beginning, and the volume of discharge is equal to the volume of run-off, then substracting the volume of discharge from the volume of rainfall we obtain a remainder which represents the volume of evaporation and is the actual amount of water which was lost from the drainage area during the given interval by evaporation processes. Now suppose a number of evaporation pans be located in this drainage area, and the depth of water lost from each pan to the air by evaporation in this interval of time be measured and recorded. Then by an appropriate integration process (or simple multiplication if no variation is observed from pan to pan within the region) the total volume of water that would be lost to the air over the region in the interval *were an unlimited supply of water kept available* could be computed. It is evident that for most regions of the earth's land surface the volume of evaporation computed from evaporation pan observations would exceed the volume of water obtained by subtracting the volume of run-off from the volume of rainfall. In keeping with the definitions just given, we say that in general observations obtained from evaporation pans represent evaporativity and very seldom represent evaporation.

All the terms defined in the first three articles, together with the units in which they are expressed, are tabulated below.

Throughout the first three sections of the present article, evaporation has been approached from two different points of view, viz. (1) that evaporation is independent of the amount of water remaining with the soil; and (2) that it is so dependent. Thus there are two sets of equations: One set applying to the first condition; the other to the second. Both sets have been derived for the sake of completeness. It would seem that in the eastern part of the United States the soil seldom becomes water-logged except in winter and early spring, and at these times of the year the rate of evaporation is very low anyway and probably could safely be neglected. The soil is not likely to become water-logged at other times of the year even though the most intense rains do occur in summer. Hence, when it is necessary to consider evaporation, it would seem that only the equations derived on the second assumption above would be required. Further comments on this question will be made when the theory here developed is applied to actual observations.

TERMS RELATED TO RUN-OFF

Term	Symbols	Units in which expressed
Run-off	$\int_0^t z\,dt$	Inches.
Rate of run-off	z	Inches per hour.
Volume of run-off	$\int_0^t A z\,dt$ or $\int\int\int z\,dz\,dw\,dt$	Mile-inches.
Volume of rate of run-off	$Az = Z$ or $\int\int z\,dz\,dw$	Miles-inches per hour.

TERMS RELATED TO RAINFALL

Rainfall	R	Inches.
Rate of rainfall	$\frac{dR}{dt} = r$	Inches per hour.
Volume of rainfall	AR or $\int\int\int r\,dz\,dw\,dt$	Mile-inches.
Volume of rate of rainfall	Ar or $\int\int r\,dz\,dw$	Mile-inches per hour.

TERMS RELATED TO EVAPORATION

Evaporation	$\int_0^t E\,dt$	Inches.
Rate of evaporation	E	Inches per hour.
Volume of evaporation	$\int_0^t AE\,dt$ or $\int\int\int E\,dz\,dw\,dt$	Mile-inches.
Volume of rate of evaporation.	AE or $\int\int E\,dz\,dw$	Mile-inches per hour.
Evaporativity	$\int_0^t \mathcal{E}\,dt$	Inches.
Rate of evaporativity	$\mathcal{E}$	Inches per hour.

TERMS RELATED TO DISCHARGE

Volume of discharge	$\int_0^t y\,dt$	Mile-inches.
Discharge	y	Mile-inches per hour.
Rate of discharge	dy/dt	Mi. in. hr^{-4}
Discharge tendency	d^2y/dt^2	Mi. in. hr^{-3}

The various assumptions which are made from time to time throughout this series of articles are of two very different kinds: First are the *special* assumptions, of which may be mentioned the assumptions that the drainage area is rectangular, the rate of rainfall is constant, the velocity of the water is constant, etc. These special assumptions will one by one be removed; they are made in order to have the early theoretical treatment tractable. Second are the *fundamental* assumptions. The first fundamental assumption, made in the first paper, is that the rate of run-off from a parcel of ground at any given time is directly proportional to the amount of water remaining with the soil at that time. No fundamental assumptions were made in the second paper. In this third paper a second and a third assumption are made: The second is: When the soil is not water-logged, the evaporation at any given instant is directly proportional to the product of the amount of water remaining with the soil by the evaporativity at that instant. The third is: When transpiration is constant, the rate of run-off at any given time is directly proportional to the amount of water remaining with the soil at that time; when the latter is constant, the rate of run-off at any given time is inversely proportional to the transpiration.

These fundamental assumptions are believed to be plausible, and to be close approximations to, if not precisely, what occurs in nature. They have been made not in order to have the mathematical treatment tractable but because no exact observations of these phenomena are available.

[1] These terms appear on p. 403 of *Transactions of the American Geophysical Union* (1935).

It will be pointed out in the fourth section of this paper that although the third fundamental assumption must be considered when dealing with the rate of run-off, it can safely be disregarded when dealing with stream flow from a drainage area of appreciable size.

In regard to the question of evaporation and its effect on stream flow, despite the fact that for the eastern part of the United States only about one-fourth of the mean annual rainfall runs off while approximately three-fourths evaporates; nevertheless, in a rain of sufficient heaviness and intensity to cause a flood the part which evaporates before the time of a flood crest is relatively small and usually has a negligible effect on the height of the flood crest. The hydrographs in the fifth section clearly show this.

PART II

SECTION 1: RUN-OFF CORRECTED FOR EVAPORATION

The symbols in this paper have the same meanings given them in the preceding papers with this exception: $\phi(t)$ henceforth represents *depth* of water remaining with the soil (not the *volume* as stated on page 318 of the first paper).

Equation (2) of paper I will now be generalized.

A first generalization will be developed on the assumption that the amount of water remaining with the soil is sufficiently great for the rate of evaporation to be independent thereof. The rate of evaporation is a function of the wind, temperature, relative humidity, and possibly other things also, but for the present purpose the rate of evaporation can be regarded simply as a function of time. As evaporation may be considered to begin at the instant the rain stops, that is, when $t=t_0$ (or when $t'=t-t_0=0$) let this function be $E(t')$. After the rain stops, the volume of water remaining with the soil at any given time is equal to the volume which fell as rain less the volume which ran off while it was raining, less the volume which has run off during the interval since the rain stopped, less the volume which has evaporated during this same interval. Expressed in symbols:

$$A\phi(t)=\int_0^{t_0} Ardt-\int_0^{t_0} Azdt-\int_{t_0}^{t} Azdt-\int_{t_0}^{t} AE(t')dt.$$

In accordance with the first fundamental assumption, $\phi(t)$ can be replaced by cz, and on doing this and differentiating we get

$$cAdz=-Azdt-AE(t')dt.$$

Clearly $dt=dt'$; and dividing by $cAdt'$ and transposing,

$$\frac{dz}{dt'}+\frac{1}{c}z=-\frac{1}{c}E(t'),$$

a linear differential equation of the first order.[1]

The integrating factor is

$$e^{\int\frac{dt'}{c}}=e^{\frac{t'}{c}},$$

hence

$$e^{\frac{t'}{c}}\frac{dz}{dt'}+\frac{1}{c}e^{\frac{t'}{c}}z=-\frac{1}{c}E(t')e^{\frac{t'}{c}},$$

and

$$\left[ze^{\frac{t'}{c}}\right]_0^{t'}=\int_0^{t'}-\frac{1}{c}E(t')e^{\frac{t'}{c}}dt.$$

Now $z=z_0$ when $t'=0$, that is, at the time the rain stops; hence, evaluating the left member, transposing and multiplying by $e^{-\frac{t'}{c}}$, we have finally:

$$z=e^{\frac{-t'}{c}}\left[z_0-\frac{1}{c}\int_0^{t'}E(t')e^{\frac{t'}{c}}dt'\right]. \qquad \text{(C-2)}$$

Equation (C–2) is the first generalized form of equation (2). It should be noted that when $E(t')=0$ then equation (C–2) reduces to equation (2) as it should.

A second generalized form of equation (2) will next be derived. Suppose that at the time the rain stops the amount of water remaining with the soil is not sufficiently great for the rate of evaporation to be independent thereof. In this case the rate of evaporativity can be regarded as a function of time. Let this function be $\mathcal{E}(t')$. Let $\phi(t')$ be the depth of water remaining with the soil at time t'; then in accordance with the second fundamental assumption, the evaporation at time t' is given by $\kappa\{E(t')\}=\phi(t')\,\mathcal{E}(t')$, where κ is a constant of proportionality. On substituting this value of $E(t')$ in the linear differential equation given above, we get

$$\frac{dz}{dt'}+\frac{1}{c}z=-\frac{1}{c\kappa}\phi(t')\,\mathcal{E}(t').$$

As before, in accordance with the first fundamental assumption $\phi(t')$ can be replaced by cz; then we have

$$\frac{dz}{dt'}+\frac{1}{c}z=-\frac{1}{\kappa}z\,\mathcal{E}(t').$$

Clearly, this can be written in the form

$$\frac{dz}{z}=-\left(\frac{1}{c}+\frac{1}{\kappa}\mathcal{E}(t')\right)dt';$$

and by integrating

$$\log z=-\frac{t'}{c}-\frac{1}{\kappa}\int\mathcal{E}(t')dt'+\text{const.}$$

Then from the definition of a logarithm and the fact that $z=z_0$ when $t'=0$, we have finally

$$z=z_0e^{-\frac{t'}{c}-\frac{1}{\kappa}\int_0^{t'}\mathcal{E}(t')dt'} \qquad \text{(C-2f)}$$

Equation (C–2f) is the second generalized form of equation (2). When $\mathcal{E}(t')=0$ then equation (C–2f) reduces to equation (2) as it should. It is important to bear in mind that equation (C–2f) was derived on the assumption that the amount of water remaining with the soil at the time the rain stops is not great enough for the rate of evaporation to be independent thereof.

As already explained, c is a time constant and is measured in hours. The constant κ is a depth (length) constant and is measured in inches. It represents the depth of water which is just sufficient to saturate the soil enough to make the rate of evaporation independent of the amount of water remaining with the soil. This depth,[2] necessary to produce just this degree of saturation, varies with the condition of the soil at the beginning of the rain. If a rain is so gentle that all the water soaks into the soil (that is, there is no *surface* run-off), and also lasts just long enough to bring about this degree of soil saturation, then κ is equal to cz_0.

[1] It may be noted that both equations (1) and (2) in the first paper could have been derived by making use of some of the elementary theory of differential equations, instead of the more elementary processes actually used.

[2] It should be emphasized that stream flow can be considered as arising from three causes, namely: (1) Surface run-off from the last rain in the river basin; (2) ground water run-off from this last rain; (3) ground water run-off from antecedent rains; and in all the statements here being made about the constants c and κ the stream flow due to the third cause is ignored. In other words, κ represents the depth as stated only insofar as the stream flow from a *single* rain is being represented.

From the above it is evident that κ can be regarded as known; and it is known at the beginning of the rain. If the rain is so heavy and so long that after the rain stops equation (C–2) applies, then this equation should be used only for a limited range. The variable z in equation (C–2) should be replaced by the constant $\frac{\kappa}{c}$ and the resulting equation solved for t; let this value of t be $\bar{t}$. Then $\bar{t}$ represents the time at which the amount of water with the soil is such that thereafter the rate of evaporation is dependent on the amount which remains. It is evident then that equation (C–2) applies on the range $0 \leqq t' \leqq \bar{t}$ (or $t_0 \leqq t \leqq \bar{t}+t_0$) and equation (C–2f) applies on the range $\bar{t} \leqq t' \leqq \infty$ (or $\bar{t}+t_0 \leqq t \leqq \infty$). If the rain is such that when the rain stops, the evaporation is dependent on the amount of water remaining with the soil, then equation (C–2f) applies on the range $0 \leqq t' \leqq \infty$.

In the first paper the discharge equations were verified by integrating them between the limits of the respective ranges over which they apply, and ascertaining that the sum of the integrals thus obtained is equal to the volume of rainfall which occurs over the drainage area. The same principle will now be used to verify the run-off equations just obtained by showing that the rainfall is equal to the sum of the run-off and the evaporation. First, suppose the amount of water remaining with the soil at the time the rain stops is small enough for the evaporation to be dependent on this amount. The depth of water remaining with the soil at the time the rain stops is

$$\phi(t_0)=\int_0^{t_0} r dt-\int_0^{t_0} r\left(1-e^{-\frac{t}{c}}\right)dt$$
$$=rc\left(1-e^{-\frac{t_0}{c}}\right).$$

The sum of the run-off and the evaporation is

$$\int_{t_0}^{\infty} z dt+\int_0^{\infty} E(t')dt'=\int_0^{\infty} z_0 e^{-\frac{t'}{c}-\frac{1}{\kappa}\int_0^{t'}\varepsilon(t')dt'}dt'$$
$$+\int_{t_0}^{\infty}\frac{1}{\kappa}\phi(t')\varepsilon(t')dt'$$
$$=\int_0^{\infty} z_0\left(1+\frac{c}{\kappa}\varepsilon(t')\right)e^{-\frac{t'}{c}-\frac{1}{\kappa}\int_0^{t'}\varepsilon(t')dt}dt'=$$
$$cz_0\left[-e^{-\frac{t'}{c}-\frac{1}{\kappa}\int_0^{t'}\varepsilon(t')dt'}\right]_0^{\infty}=cz_0=rc\left(1-e^{-\frac{t_0}{c}}\right),$$

which is equal to the depth remaining with the soil at the time the rain stops.

Suppose now that $rc\left(1-e^{-\frac{t_0}{c}}\right)$ is so great that for a while the rate of evaporation is independent of this depth. In this case equation (C–2) is integrated between the limits 0 and $\bar{t}$. The evaporation plus the runoff from the time the rain stops to the time $\bar{t}$ is

$$\int_0^{\bar{t}} E(t')dt'+\int_0^{\bar{t}} e^{-\frac{t'}{c}}\left[z_0-\frac{1}{c}\int_0^{\bar{t}} E(t')e^{\frac{t'}{c}}dt'\right]dt'=$$
$$\int_0^{\bar{t}} E(t')dt'+z_0\int_0^{\bar{t}} e^{-\frac{t'}{c}}dt'+\int_0^{\bar{t}}\left(-\frac{1}{c}e^{-\frac{t'}{c}}\right)\left(\int_0^{t'} E(t')e^{\frac{t'}{c}}dt'\right)dt'=$$
$$\int_0^{\bar{t}} E(t')dt'+cz_0\left(1-e^{-\frac{\bar{t}}{c}}\right)+\left[\frac{t'}{e^c}\int_0^{t'} E(t')e^{\frac{t'}{c}}dt'-\int_0^{t'} E(t')dt'\right]_0^{\bar{t}}$$
$$=cz_0\left(1-e^{-\frac{\bar{t}}{c}}\right)+e^{-\frac{\bar{t}}{c}}\int_0^{\bar{t}} E(t')e^{\frac{t'}{c}}dt'.$$

The depth remaining at time t is therefore

$$cz_0 e^{-\frac{t}{c}}-e^{-\frac{t}{c}}\int_0^{t'} E(t')e^{\frac{t'}{c}}dt'$$

and from the definition of $\bar{t}$ this must equal κ. The evaporation plus the runoff from the time $\bar{t}$ till all water has disappeared from the soil is

$$\int_{\bar{t}}^{\infty} z dt'+\int_{\bar{t}}^{\infty} E(t')dt'=\kappa\int_0^{\infty}\left(1+\frac{c}{\kappa}\varepsilon(t')\right)e^{-\frac{t'}{c}-\frac{1}{\kappa}\int_0^{t'}\varepsilon(t')dt'}dt'$$
$$=\kappa \text{ as it should.}$$

SECTION 2: DISCHARGE FROM RECTANGLE CORRECTED FOR EVAPORATION

Equations will now be obtained for a rectangular drainage area, under the assumption that the amount of water remaining with the soil at the time the rain stops is not great enough to make the evaporation independent thereof. It is further assumed in this simple case that the rate of evaporativity is constant.

Undoubtedly there is a small amount of evaporation while the rain is in progress, but it is here assumed to be negligible, and for this reason no modification is necessary in equations (3) and (4). Equation (5) applies on the range $t_0+\frac{L}{v} \leqq t \leqq \infty$, and it follows by reasoning similar to that given in the first paper that on this range the discharge is obtained by integrating the volume of rate of runoff over the entire drainage area. Making use of equation (C–2f) the volume of rate of runoff from the infinitesimal strip, Wdx, at distance x above the gaging station is given by

$$Wzdx=Wz_0 e^{-\left(t'-\frac{x}{v}\right)/c-\frac{1}{\kappa}\varepsilon\left(t'-\frac{x}{v}\right)}dx$$
$$=Wz_0 e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\left(t'-\frac{x}{v}\right)}dx$$

On integrating $Wzdx$ between the limits 0 and L we get

$$y=Wz_0\frac{c\kappa v}{\kappa+c\varepsilon}\left[e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\left(t'-\frac{L}{v}\right)}-e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)t'}\right]$$

Since $z_0=r\left(1-e^{-\frac{t_0}{c}}\right)$ and $t'=t-t_0$ we have finally

$$y=Wrcv\left(1-e^{-\frac{t_0}{c}}\right)\frac{\kappa}{\kappa+c\varepsilon}\left[e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\left(t-t_0-\frac{L}{v}\right)}e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)(t-t_0)}\right]$$

This is equation (26). When $\varepsilon=0$ equation (26) reduces to equation (5) as it should.

If $t_0>\frac{L}{v}$ then for the range $t_0 \leqq t \leqq t_0+\frac{L}{v}$ equation (6) requires modification. It follows by reasoning similar to that of the first paper, and that used in obtaining equation (26), that on this range the discharge is

$$y=\int_{x_0}^{L}\left[Wr\left(1-e^{-\frac{1}{c}\left(t-\frac{x}{v}\right)}\right)\right]dx+\int_{\cdot}^{x_0} Wz_0 e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\left(t'-\frac{x}{v}\right)}dx.$$

On performing the integration indicated, recalling that $x_0=(t-t_0)v$, and simplifying, we get finally

$$y=\left[Wr\,L-(t-t_0)v+cv\left(e^{-\frac{t_0}{c}}-e^{-\frac{1}{c}\left(t-\frac{L}{v}\right)}\right)\right]$$
$$+Wrcv\left[\left(1-e^{-\frac{t_0}{c}}\right)\frac{\kappa}{\kappa+c\varepsilon}\left\{1-e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)(t-t_0)}\right\}\right] \qquad (27)$$

When $\varepsilon=0$ equation (27) reduces to equation (6) as it should.

If $t_0<\frac{L}{v}$, equation (9) requires modification for the range $t_0\leqq t\leqq\frac{L}{v}$. By reasoning similar to that just used, as well as from the explanations in the first paper, it follows that on this range the discharge is given by

$$y=Wrv\left[t_0+c\left(1-e^{-\frac{t_0}{c}}\right)\left(\frac{\kappa}{\kappa+c\varepsilon}\left\{1-e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)(t-t_0)}\right\}-1\right)\right], \quad (28)$$

and this equation reduces to equation (9) when $\varepsilon=0$.

As previously explained, the derivatives, with respect to t, of equations (3) and (4) are everywhere positive. It follows readily that the derivative of equation (28) is everywhere positive, and that for equation (26) is everywhere negative. Hence whether $t_0\gtrless L/v$ the time of the flood crest is obtained by equating the derivative of equation (27) with respect to time to zero and solving. If t_c represent the time of the crest, the equation obtained by equating the derivative of equation (27) to zero cannot be solved explicitly for t_c. However, in the case of y_c the maximum discharge, we can resort to the device, which was used several times in the second paper, of multiplying equation (27) by $e^{\frac{t}{c}}$, differentiating the equation thus obtained, setting $dy/dt=0$ and finally multiplying by $ce^{-\frac{t}{c}}$.

Or doing this we have

$$y_c=Wr\left[L-(t_c-t_0)v+cv\left(1-e^{-\frac{t_0}{c}}\right)\left\{\frac{\kappa}{\kappa+c\varepsilon}\left(1+\frac{c\varepsilon}{\kappa}e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)(t-t_0)}\right)-1\right\}\right] \quad (29)$$

When $\varepsilon=0$ equation (29) reduces to equation (8) as it should.

We are now ready to consider the case when the amount of water remaining with the soil at the time the rain stops is so great that the rate of evaporation is independent thereof. Here we further assume that the rate of evaporation, from the time the rain stops to the time the amount of water remaining with the soil is small enough to make the rate of evaporation dependent thereon, is constant.

If E is constant, as we are now assuming, equation (C—2) takes the form $z=e^{-\frac{t'}{c}}\left[z_0-E\left(e^{\frac{t'}{c}}-1\right)\right]$, and the contribution to the discharge from the infinitesimal strip Wdx at distance x above the gaging station is $W\left[z_0e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}+E\left(e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}-1\right)\right]dx$. If $t_0<\frac{L}{v}$, then on the range $t_0\leqq t\leqq\frac{L}{v}$ equation (9) requires modification; and on this range the discharge is given by

$$\begin{aligned}y&=\int_{x_0}^{tv}Wr\left[1-e^{-\frac{1}{c}\left(t-\frac{x}{v}\right)}\right]dx\\&+\int_0^{x_0}W\left[z_0e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}+E\left(e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}-1\right)\right]dx\\&=Wrv\left[t_0+ce^{-\frac{t}{c}}\left(1-e^{-\frac{t_0}{c}}\right)\right]\\&-WEv\left[t-t_0+c\left(e^{-\frac{1}{c}(t'-t_0)}-1\right)\right].\end{aligned} \quad (30)$$

Equation (30) holds on the range $t_0\leqq t\leqq L/v$ with the further restriction that $z>\frac{\kappa}{c}$. When $\varepsilon=0$, equation (30) reduces to equation (9).

If $\frac{L}{v}\leqq t\leqq t_0+\frac{L}{v}$ and $t>t_0$, equation (6) must be changed. For this range (with the additional restriction that $z>\kappa/c$ of course) the discharge is given by

$$\begin{aligned}y&=Wr\left[L-(t-t_0)v+cv\left\{1+e^{-\frac{t}{c}}\left(1-e^{\frac{L}{cv}}-e^{\frac{t_0}{c}}\right)\right\}\right]\\&-WEv\left[t-t_0+c\left(e^{-\frac{1}{c}(t-t_0)}-1\right)\right],\end{aligned} \quad (31)$$

which reduces to equation (6) when E=0.

If $t_0+\frac{L}{v}\leqq t\leqq\infty$, with the additional restriction that $z>\frac{\kappa}{c}$ of course, the discharge is given by

$$\begin{aligned}y&=Wrcve^{-\frac{t}{c}}\left[e^{\frac{1}{c}\left(\frac{L}{v}+t_0\right)}-e^{\frac{L}{cv}}-e^{\frac{t_0}{c}}+1\right]\\&-WE\left[L+cve^{-\frac{1}{c}(t-t_0)}\left(1-e^{\frac{L}{cv}}\right)\right],\end{aligned} \quad (32)$$

which reduces to equation (5) when E=0.

Suppose that $z=\frac{\kappa}{c}$ at time $t=t_0+\bar{t}$, and suppose further $t_0+\bar{t}\geqq t_0+\frac{L}{v}$; then on the range $t_0+\bar{t}\geqq t\geqq\infty$ the discharge is given by

$$\begin{aligned}y&=\int_{(t'-\bar{t})v}^{L}W\left[z_0e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}+E\left(e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}-1\right)\right]dx\\&+\int_0^{(t'-\bar{t})v}W\frac{\kappa}{c}e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\left(t'-\frac{x}{v}\right)}dx.\end{aligned}$$

On performing the integration and simplifying we finally get

$$\begin{aligned}y&=Wrcv\left(e^{-\frac{1}{c}(t-t_0-L/v)}-e^{-\frac{\bar{t}}{c}}-e^{-\frac{1}{c}(t-L/v)}+e^{-\frac{1}{c}(\bar{t}+t_0)}\right)\\&+WEcv\left(e^{-\frac{1}{c}(t-t_0-L/v)}-e^{-\frac{\bar{t}}{c}}\right)-WE\left(L-\{t-t_0-\bar{t}\}v\right)\\&+Wkv\frac{\kappa}{\kappa+c\varepsilon}\left(e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\bar{t}}-e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)(t-t_0)}\right).\end{aligned} \quad (33)$$

Equation (33) holds on the range $\bar{t}\leqq t'\leqq\bar{t}+\frac{L}{v}$. When $t=\bar{t}+t_0$ equation (33) reduces to the form

$$\begin{aligned}y&=WEcve^{-\bar{t}/c}\left(e^{L/cv}-1\right)-WEL+\\&+Wrcve^{-\frac{1}{c}(\bar{t}+t_0)}\left(e^{\frac{1}{c}\left(\frac{L}{v}+t_0\right)}-e^{L/cv}-e^{t_0/c}+1\right).\end{aligned} \quad (33a)$$

When t is set equal to $t+t_0$ in equation (32), the latter takes the form of equation (33a) also, as would be expected. When $t=\bar{t}+t_0+L/v$ equation (33) reduces to the form

$$y=Wkv\frac{\kappa}{\kappa+c\varepsilon}\left(e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)\bar{t}}-e^{-\left(\frac{1}{c}+\frac{\varepsilon}{\kappa}\right)(\bar{t}+L/v)}\right) \quad (33b)$$

Equation (26) involves the factor $z_0=r\left(1-e^{-\frac{t_0}{c}}\right)$. If this factor be replaced by κ/c then equation (26) reduces to the

form of equation (33b) when $t=t+t_0+L/v$. This fact requires some explanation. If, at the beginning of a rain, κ be the depth of water (in inches) required to produce just enough saturation of the soil for the rate of evaporation to be independent of the water which remains, and if this rain fell and saturated the soil instantaneously, then $\kappa=R$, the depth of the rain. However, in nature there will never be such instantaneous rains; and the depth of rain required to produce this saturation of the soil is $\int_0^{t_0} r(1-e^{-t/c})\,dt$ less than rt_0; that is to say, the depth of rainfall, rt_0, must be diminished by the run-off while the rain is in progress, and κ is then equal to $rc\,(1-e^{-t_0/c})$, or in other words $\kappa=z_0c$ *provided* t_0 does not exceed the time required to produce *exactly* this degree of saturation. Clearly, in general, t_0 will either be less than or greater than this time. If t_0 is less than this time, the rate of evaporation is dependent on the amount which remains and therefore one of the equations (26), (27) or (28) applies. Each of these three equations involves the factor $z_0=r\,(1-e^{-t/c})$. If, however, t_0 exceeds the time necessary for κ inches of rainfall to accumulate and remain with the soil, then equations (26), (27) and (28) are not at once applicable but instead one of equations (30), (31) or (32) applies; equation (32) does not in this case apply on the range $t_0+\frac{L}{v}\leqq t\leqq\infty$, because eventually the water remaining with the soil will diminish to a value that will make the rate of evaporation dependent on this amount. Of course equation (32) would apply on this range if the soil were impervious and no rain soaked *into* the soil, because as long as there were free water above an impervious soil the supply of water available insofar as the effect on the rate of evaporation is concerned could be regarded as unlimited. When the water remains with the soil long enough after the rain has stopped for the rate of evaporation to become dependent thereon an equation of the form of (26) applies; but in this case we cannot use the factor $z_0=r(1-e^{-t_0/c})$, because t_0 *exceeds* the time required for z_0 to become just equal to κ/c. Now $\bar{t}$ represents the time, after the rain stops, at which the water remaining with the soil has receded to a value such that the rate of evaporation will thereafter be dependent on the amount of water which remains. Hence when t_0 exceeds the value for κ to be equal to $rc\,(1-e^{-t_0/c})$, and if $\bar{t}>L/v$, then equation (32) applies on the range $t_0+L/v\leqq t\leqq t_0+\bar{t}$, equation (33) on the range $t_0+\bar{t}\leqq t\leqq t_0+\bar{t}+L/v$, and equation (26), after the factor $z_0=r\,(1-e^{-t_0/c})$ is replaced by κ/c, applies on the range $t_0+\bar{t}+L/v\leqq t\leqq\infty$.

If both E and $\mathcal{E}$ are equal to zero, which is practically equivalent to saying that the air is so still and cloudy and damp that there can be no evaporation, we can replace $\bar{t}$ by any value of t' whatever; and equation (33) then reduces to equation (5) as it should.

If $\bar{t}<L/v$ equations (30) and (31) will not apply on the ranges stated, since in this case z has receded to a value equal to or less than κ/c. Equations for this situation will not be obtained. Their derivation, if desired, is perfectly straight-forward, following the reasoning used in getting equation (33).

It can be shown that the derivatives of equations (32) and (33) with respect to t are everywhere negative; that is, the flood crest cannot be given by these equations. If we differentiate equation (31) with respect to t we get

$$dy/dt=Wrv\left[-1-e^{-t/c}\left(1-e^{L/cv}-e^{t_0/c}\right)\right]-WEv\left[1-e^{-\frac{1}{c}(t-t_0)}\right]$$

If we set this derivative equal to zero, t is replaced by t_c, the time of the flood crest. Solving for t_c, we get

$$t_c=c\left[\log\left\{r\left(e^{L/cv}+e^{t_0/c}-1\right)-Ee^{\frac{t_0}{c}}\right\}-\log\left\{r-E\right\}\right]. \qquad (34)$$

The maximum discharge, y_c, is obtained by using the same device as in deriving equation (29); and from equation (31) we get in this way

$$y_c=Wr[L-(t_c-t_0)v]-WE(t_c-t_0)v. \qquad (35)$$

When $E=0$ equation (34) reduces to equation (7), and equation (35) to equation (8), as they should.

The question arises whether equation (30) furnishes, in certain cases, the maximum discharge. To consider this take equation (C–2). From this equation it is evident $z=0$ when $z_0=\frac{1}{c}\int_0^{t'}E(t')e^{t'/c}dt'$. Equation (C–2) is only applicable till the time $\bar{t}$ and since after the time represented by the solution of this last equation for t' equation (C–2) gives negative values for the run-off it is clear that $\bar{t}$ cannot possibly exceed the value obtained by solving this equation. If $E(t')$ is constant this equation becomes

$$z_0=E(e^{t'/c}-1) \text{ or } e^{t'/c}=1+\frac{z_0}{E} \text{ whence } t'=c\,\log\left(1+\frac{z_0}{E}\right).$$

Thus since equation (C–2) is not applicable after this time neither is equation (30) which was based on equation (C–2). The derivative of equation (30) is

$$\frac{dy}{dt}=Wrv\left(e^{t_0/c}-1\right)e^{-t/c}-WEv\left(1-e^{-\frac{1}{c}(t-t_0)}\right)$$

equate this to zero and solve: $t_c=c\,\log\left[\frac{r}{E}\left(e^{t_0/c}-1\right)+e^{t_0/c}\right]$

But equation (30) cannot possibly hold after

$$t=t_0+c\,\log\,(1+z_0/E).$$

In Nature, it will never even hold up to this value. Since $z_0=r(1-e^{-t_0/c})$ and $t_0=c\,\log\,e^{t_0/c}$ we have $t=c\,\log\left[e^{t_0/c}\left\{1+r/E\left(1-e^{-t_0/c}\right)\right\}\right]$. That is, t_c representing the point where the derivative of equation (30) takes the zero value equals this value up to which equation (30) will never apply in Nature. Therefore equation (30) cannot have a maximum on the range for which it holds.

SECTION 3: DISCHARGE FROM ANY DRAINAGE AREA CORRECTED FOR EVAPORATION

The equations of section 2, wherein the width of the drainage area, and the rate of evaporation (or evaporativity) were considered constant, serve as a simple illustration of, and an introduction to, the underlying principles involved in correcting the discharge for evaporation in general. More general equations will now be developed in which neither the width of the drainage area nor the rate of evaporation (or evaporativity) is treated as constant.

The same mathematical restrictions are placed on $W(x)$, the function which represents the width of the drainage area, as in the second paper. The following mathematical restrictions are placed on the functions $E\,(t')$ and $\mathcal{E}\,(t')$ which represent the rate of evaporation and rate of evaporativity respectively:

1. They are identically zero when $t'<0$; in other words before the rain stops there is no evaporation.
2. They shall be single valued, except at points of discontinuity where they shall be two-valued.
3. They shall be everywhere finite.
4. They may assume an unlimited number of zero values, but may not assume any negative value.
5. They shall not have more than a finite number of discontinuities on a finite range.

When equations (C–2) and (C–2f) were derived, no explicit assumptions were made about the functions $E(t')$ and $\mathcal{E}(t')$. Obviously these equations are valid if the functions are continuous; but it should be noted that they also hold when $E(t')$ and $\mathcal{E}(t')$ are subject merely to the more general restrictions just stated.

Each of the restrictions listed is justified by the physical nature of the problem. The fourth restriction may require special comment since evaporation is sometimes loosely spoken of as negative rainfall. To regard the evaporation which may take place while rain is in progress as negative rainfall is certainly logical. However, it does not seem to be convenient to treat evaporation in this way after the rain stops. Neither does it seem to be altogether convenient to treat the occasional light shower which may occur after the main heavy flood-causing rain as negative evaporation. Further developments may make such treatment desirable but for the present the fourth restriction is imposed.

In the following developments the discontinuity which may take place in the constant, c, during and after a rain is ignored, just as it has been previously. It was explained in the first paper that the constant c may be thought of as consisting of two parts: one, c', due to the fact that water soaks *into* the soil and the other, c'', due to the fact that water sometimes remains *upon* the soil. The constant $c''=0$ when and only when the soil is saturated. The constant $c'=0$ when and only when the soil is not saturated and also the rate of rainfall is less than the infiltration rate. If the rate of rainfall exceed the infiltration rate and the soil is not saturated then neither c' nor c'' is zero. Both c' and c'' are never simultaneously zero. After an intense rain water may remain upon the soil for some time after the rain stops even though the soil is not saturated because the rate of rainfall exceeded the infiltration rate. In this case the rate of evaporation is independent of the depth of water remaining with the soil until and only until there is no water remaining upon the soil. At this instant there is a discontinuity in the constant c. The behavior of the constant c will be fully discussed in the fifth paper of this series.

Consider first the case where the soil contains so much water at the time the rain stops that the rate of evaporation is independent of the amount which remains. The rate of run-off from each infinitesimal strip, $W(x)dx$, above the gaging station is given by equation (C–2). By integrating this expression between the limits 0 and L, making due allowance for the time it takes for water to flow from where it fell as rain to the gaging station, we have

$$y=\int_0^L W(x)e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}\left[z_0-\frac{1}{c}\int_0^{(t'-x/v)}E(t')e^{\frac{t'}{c}}dt'\right]dx$$

$$=e^{-t'/c}\left[z_0\int_0^L W(x)e^{x/cv}dx\right.$$

$$\left.-\int_0^L\frac{1}{c}W(x)e^{x/cv}\left\{\int_0^{(t'-x/v)}E(t')e^{\frac{t'}{c}}dt'\right\}dx\right] \qquad \text{(C–5)}$$

Equation (C–5) expresses the discharge as a function of t, and holds on the range $t_0+L/v\leqq t\leqq\infty$ with the additional restriction that $z>\kappa/c$. When $E(t')\equiv 0$ equation (C–5) becomes equation (B–5). For this reason we call it the second generalized form of equation (5). When both $W(x)$ and $E(t')$ are constants, equation (C–5) reduces to equation (32). When $t=t_0+L/v$, equation (C–5) takes the form

$$y=e^{-L/cv}\left[z_0\int_0^L W(x)e^{x/cv}dx\right.$$

$$\left.-\int_0^L\frac{1}{c}W(x)e^{x/cv}\left\{\int_0^{(L-x)/v}E(t')e^{t'/c}dt'\right\}dx\right] \qquad \text{(C–5a)}$$

As stated in section 2, about equations (3) and (4), equations (B–3) and (B–4) require no correction for evaporation. Equations (B–6) and (B–9) do, however. The flood crest occurs on the range for which these equations apply. Equation (C–6) below, now to be obtained, holds on the range $t_0\leqq t\leqq t_0+L/v$ with the two additional restrictions that $t>L/v$ and $z>\kappa/c$. By reasoning similar to that used in all previous cases when this range was considered, it follows that for this range the discharge is given by

$$y=\int_{x_0}^L r\left(1-e^{-\frac{1}{c}(t-x/v)}\right)W(x)dx+$$

$$\int_0^{x_0}e^{-\frac{1}{c}(t'-x/v)}\left[z_0-1/c\int_0^{(t'-x/v)}E(t')e^{t'/c}dt'\right]W(x)dx.$$

Since $t'=t-t_0$, $x_0=(t-t_0)v$, and $z_0=r(1-e^{-t_0/c})$ the above expression can be written in the form

$$y=r\left[\int_{x_0}^L W(x)dx-e^{-t/c}\int_0^L W(x)e^{x/cv}dx+\right.$$

$$\left.e^{-(t-t_0)/c}\int_0^{x_0}W(x)e^{x/cv}dx\right]-$$

$$\frac{1}{c}e^{-(t-t_0)/c}\int_0^{x_0}W(x)e^{x/cv}\left[\int_0^{t-t_0-x/v}E(t')e^{t'/c}dt'\right]dx. \qquad \text{(C–6)}$$

When $E(t')\equiv 0$ equation (C–6) reduces to equation (B–6) and therefore is called the second generalized form of equation (6). When both $W(x)$ and $E(t')$ are constants equation (C–6) becomes equation (31). When $t=t_0$ equation (C–6) becomes equation (B–4a), and when $t=t_0+L/v$ equation (C–6) becomes equation (C–5a). When $t=L/v$ equation (C–6) takes the form

$$y=r\left[\int_{L-t_0v}^L W(x)dx-e^{-L/cv}\int_0^L W(x)e^{x/cv}dx+\right.$$

$$\left.e^{-\frac{1}{c}(L/v-t_0)}\int_0^{L-t_0v}Wxe^{x/cv}dx\right]-$$

$$\frac{1}{c}e^{-\frac{1}{c}(L/v-t_0)}\int_0^{L-t_0v}W(x)e^{x/cv}\left[\int_0^{L/v-t_0-x/v}E(t')e^{t'/c}dt'\right]dx. \qquad \text{(C–6a)}$$

For the case when the rate of evaporation is independent of the water remaining with the soil, we still must consider the range $t_0\leqq t\leqq t_0+L/v$ with the two additional restrictions that $t_0<L/v$ and $z>\kappa/c$. To save space, however, the equation which applies to this range, which would be numbered (C–9), is not given; this equation (C–9) can be obtained by substituting tv for L in equation (C–6). Similar statements can be made for equation

(C–9) as were made for (C–6) when $E(t')\equiv 0$ and when $E(t')$ and $W(x)$ are constants.

We proceed to find an expression for the time of the maximum discharge, and for the maximum discharge itself. By differentiating equation (C–6) with respect to t, equating to zero, simplifying, and recalling that at the time of the crest $t=t_c$, we finally get

$$re^{t/\kappa}\int_0^{t_c v-t_0} W(x)e^{x/cv}dx+e^{t/c}\int_0^{t_c v-t_0} E(t_c-t_0-x/v)W(x)dx$$
$$=r\int_0^L W(x)e^{x/cv}dx+$$
$$\frac{e^{t_0/c}}{c}\int_0^{t_c v-t_0} W(x)e^{x/cv}\left[\int_0^{t_c-t_0-x/v} E(t')e^{t'/c}dt'\right]dx. \quad \text{(C–7)}$$

The solution of equation (C–7) for t_c gives the time of the crest. If the drainage area is of such a shape that the crest may occur on the range $t_0\leqq t\leqq t_0+L/v$ where $t<L/v$ then equation (C–7) should be modified by substituting $t_c v$ for L.

An expression for the maximum discharge is obtained by resorting to the usual device of multiplying equation (C–6) by $e^{t/\kappa}$, then differentiating with respect to t, setting $dy/dt=0$, and finally multiplying by $ce^{-t/c}$. We thus get

$$y_c=r\int_{t_c v-t_0}^L W(x)dx-\int_0^{t_c v-t_0} W(x)E(t_c-t_0-x/v)dx. \quad \text{(C–8)}$$

If the drainage area is such, and the rain so short, that the crest may occur before the time $t=L/v$, then $t_c v$ should be substituted for L in the above equation.

The discharge equations thus far derived in this section, and hence the expressions for the maximum discharge and time of the flood crest obtained from them, are valid only if $z_0>\kappa/c$, and then only till the time that z diminishes to the value κ/c. Discharge equations and expressions for the maximum discharge and time of flood crest will now be obtained for the case when $z_0<\kappa/c$, that is to say, when the depth of water remaining with the soil at the time the rain stops is not great enough for the rate of evaporation to be independent of it. When this is the case equation (C–2f) gives the rate of run-off for each infinitesimal strip, $W(x)dx$ above the gaging station. By integrating the product, $W(x)zdx$, between the limits 0 and L, taking account of the time required for the water to flow from where it fell as rain to the gaging station, we get

$$y=z_0\int_0^L W(x)e^{-\frac{1}{c}(t'-x/v)-\frac{1}{\kappa}\int_0^{t'-x/v}\varepsilon(t')dt'}dx. \quad \text{(C–5f)}$$

Equation (C–5f) holds on the range $t_0+L/v\leqq t\leqq\infty$ with the restriction that $z_0\leqq\kappa/c$. When $\varepsilon(t')\equiv 0$ equation (C–5f) reduces to equation (B–5) and for this reason we call it the third generalized form of equation (5). When $W(x)$ and $\varepsilon(t')$ are constants equation (C–5f) takes the form of equation (26). When $t\to\infty$ equation (C–5f) shows that $y\to 0$, which means that at a sufficiently long time after the rain stops (with no additional rains of course) the stream flow ceases. When $t=t_0+L/v$ equation (C–5f) takes the form

$$y=z_0\int_0^L W(x)e^{(L-x)/cv-1/\kappa\int_0^{(L-x)/v}\varepsilon(t')dt'}dx. \quad \text{(C–5g)}$$

Consider now the range $t_0\leqq t\leqq t_0+L/v$ with the further conditions that $t>L/v$ and $z_0\leqq\kappa/c$. Under these conditions and for this range the discharge is given by:

$$y=\int_{x_0}^L rW(x)\left(1-e^{-\frac{1}{c}(t-x/v)}\right)dx$$
$$+z_0\int_0^{x_0} W(x)e^{-\frac{1}{c}(t'-x/v)-\frac{1}{\kappa}\int_0^{t'-x/v}\varepsilon(t')dt'}dx.$$

Since $t'=t-t_0$ and $x_0=v(t-t_0)$ and $z_0=r(1-e^{-t_0/c})$ the above expression simplifies to

$$y=r\left[\int_{x_0}^L W(x)dx-e^{-t/c}\int_{x_0}^L W(x)e^{x/cv}dx\right.$$
$$\left.-(e^{-t_0/c}-1)\int_0^{x_0} W(x)e^{-\frac{1}{c}(t-t_0-x/v)-\frac{1}{\kappa}\int_0^{t-t_0-x/v}\varepsilon(t')dt'}dx\right] \quad \text{(C–6f)}$$

When $\varepsilon(t')\equiv 0$ equation C–6f) reduces to equation (B–6), and for this reason we call equation (C–6f) the third generalized form of equation (6). When both $W(x)$ and $\varepsilon(t')$ are constants equation (C–6f) becomes equation (27). When $t=t_0$, equation (C–6f) takes the form of equation (B–4a), and when $t=t_0+L/v$ equation (C–6f) becomes equation (C–5g). When $t=L/v$ equation (C–6f) has the form

$$y=r\left[\int_{L-t_0}^L W(x)dx-e^{-L/cv}\int_{L-t_0}^L W(x)e^{x/cv}dx\right.$$
$$\left.+(1-e^{-t_0/c})\int_0^{L-t_0} W(x)e^{-\frac{1}{c}(L/v-t_0-x/v)-\frac{1}{\kappa}\int_0^{L/v-t_0-x/v}\varepsilon(t')dt'}dx\right] \quad \text{(C–6g)}$$

The last discharge equation to be obtained is one for the range $t_0\leqq t\leqq t_0+L/v$ where $t<L/v$ and $z_0\leqq\kappa/c$. For this range and these additional conditions equation (C–9f) applies; to save space it is not given; it can be immediately obtained from equation (C–6f) by substituting tv for L. Corresponding statements can be made about the form to which equation (C–9f) simplifies when special assumptions are made about $W(x)$ and $\varepsilon(t')$, as were made in regard to equation (C–6f).

We next proceed to obtain expressions for the time of the flood crest and for the maximum discharge. Differentiate equation (C–6f) with respect to t, set this derivative equal to zero, and simplify, recalling that when $dy/dt=0$ the time of the flood crest is indicated by t_c and $t_c-t_0=t^*$. On doing this we have:

$$\frac{1}{e^{t_0/c}-1}\int_{t^*v}^L W(x)e^{x/cv}dx=\int_0^{t^*v} W(x)e^{x/cv-\frac{1}{\kappa}\int_0^{t^*-x/v}\varepsilon(t')dt'}dx$$
$$+\frac{c}{\kappa}\int_0^{t^*v} W(x)e^{x/cv-\frac{1}{\kappa}\int_0^{t^*-x/v}\varepsilon(t')dt'}\varepsilon(t^*-x/v)dx. \quad \text{(C–7f)}$$

The solution of equation (C–7f) for t^* gives the time of the flood crest. If the drainage area is shaped so that the crest may be reached before the time L/v, and if in this case the rain is short enough, then tv should be substituted for L in this equation.

An expression for the maximum discharge is obtained by using the usual device of multiplying equation (C–6f) by $e^{t/c}$, differentiating the equation thus obtained with respect to t, setting $dy/dt=0$ and finally multiplying by $ce^{-t/c}$. On doing this we get

$$y_c=r\int_{t^*v}^L W(x)dx-$$
$$rce^{-t^*/c}\frac{(1-e^{-t_0/c})}{\kappa}\int^{t^*v} e^{x/cv-\frac{1}{\kappa}\int_0^{t^*-x/v}\varepsilon(t')dt'}W(x)\varepsilon\left(t^*-\frac{x}{v}\right)dx$$

If the solution of equation (C–7f) for t^* shows that the time of the flood crest occurs before the time L/v, then tv should be substituted for L in equation (C–8f) to obtain the maximum discharge.

Before proceeding further, it will be useful to summarize briefly what has been accomplished thus far in the first three papers of this series. Section I of the first paper and section I of the present paper pertain to *run-off* equations. All the remaining sections, excepting section 5 of the second paper, pertain to *discharge* equations and conclusions which can be drawn from them. Of the sections dealing with discharge equations, the first three in the second paper, and the second in the present paper, consider quite special conditions; while they are instructive and interesting, nevertheless they lack generality and need not be considered further in this brief summary. The second section of the first paper, the fourth section of the second paper, and the present section are developed along closely similar lines. Thus the second section of the first paper derives the five discharge equations (3), (4), (5), (6), and (9). Likewise the fourth section of the second paper derives five discharge equations, bearing the same numbers with the letter B prefixed. The only difference between these two sets of equations is that in the former the drainage area is considered to be rectangular, while in the latter the drainage area may be of any shape encountered in nature. These equations serve to express the discharge from the time the rain begins till the time the discharge has receded to the value it had at the beginning of the rain. Two cases arise, one when the rain lasts long enough for water which fell as rain in that part of the drainage area most remote from the gage to flow to the gage; the other, when the rain did not last this long. The time required for water to flow from the most remote portion of a drainage area to the gage is called the *concentration time;* it has been expressed by L/v. The duration of the rain is expressed by t_0. Now regardless of whether the duration of the rain *exceeds* the concentration time or not, that is, whether $t_0 \gtrless L/v$, four equations are necessary to express the discharge as a function of time from the instant the rain begins till the stream flow has receded to the value it had at the time the rain began. (It is understood, of course, that in this theoretical treatment no additional rains occur after the end of the single one under consideration.) If the duration of the rain exceeds the concentration time, the four equations required are equations (3), (4), (6), and (5) in that order; if the concentration time exceeds the duration of the rain the four equations required are successively (3), (9), (6), and (5). If $t_0 > L/v$, the ranges of the equations are—

equation (3) or (B–3)	$0 \leqq t \leqq L/v.$
equation (4) or (B–4)	$L/v \leqq t \leqq t_0.$
equation (6) or (B–6)	$t_0 \leqq t \leqq t_0 + L/v.$
equation (5) or (B–5)	$t_0 + L/v \leqq t \leqq \infty.$

If $t_0 < L/v$, the ranges of the equations are

equation (3) or (B–3)	$0 \leqq t \leqq t_0.$
equation (9) or (B–9)	$t_0 \leqq t \leqq L/v.$
equation (6) or (B–6)	$L/v \leqq t \leqq t_0 + L/v.$
equation (5) or (B–5)	$t_0 + L/v \leqq t \leqq \infty.$

Throughout the second section of the first paper, the fourth section of the second paper, and the present section, much care has been taken to show that at the limits of the ranges of these equations the discharge curve, as a whole, is continuous; in the second article it was pointed out that the rate of discharge curve also is continuous at these points, but that the discharge tendency curve is discontinuous. From the physical nature of the problem, the discharge curve would naturally be expected to be everywhere continuous.

In the present section, discharge equations have been derived in which corrections are made for the evaporation which takes place after the rain stops. If the rate of evaporation is always *dependent* on the water remaining with the soil, as it actually is after many rains, then the treatment of evaporation is rather simple and the discharge curve is expressed by the four equations (B–3), (B–4), (C–6f) and (C–5f) in that order if the duration of the rain exceeds the concentration time, and successively (B–3), (C–9f), (C–6f), and (C–5f) if the concentration time exceeds the duration of the rain. On the other hand if the rate of evaporation is *always independent* of the amount of water that remains with the soil, the discharge curve is expressed by the four equations (B–3), (B–4), (C–6), and (C–5) in that order if $t_0 > L/v$, and successively by (B–3), (C–9), (C–6), and (C–5) when $t_0 < L/v$; but it is doubtful if this case ever occurs in nature. It would seem that the closest approach to such a condition would be when rain falls on ground that is deeply frozen and remains frozen until all surface water from the rain has run off. Actually when the rain lasts so long that z_0 exceeds κ/c and makes the rate of evaporation independent of the amount which remains, the rate of evaporation remains independent of this amount only so long as z exceeds κ/c. For this reason more than four equations are required to express the discharge curve. If $\bar{t}$ represents the time measured from the instant the rain stops, at which the rate of run-off recedes to the value κ/c, then for any small parcel of ground the rate of run-off is given by equation (C–2) during the interval $0 \leqq t' \leqq \bar{t}$, and by equation (C–2f) after having replaced z_0 by κ/c during the interval $\bar{t} \leqq t' \leqq \infty$. Whenever the rain lasts long enough to make z_0 exceed κ/c, six equations instead of four are necessary to represent the discharge curve.

The additional equations necessary for a complete treatment will not be derived; only an explanation of how they may be obtained, and the ranges of their applicability, are given. All the discharge equations in the three sections here summarized can be placed in one of three classes. One class comprises all those equations derived by integrating equation (1) over the drainage area, with, of course, consideration of the time required for the water to flow from where it fell as rain to the gage. In the second class are placed all those equations derived by integrating any one of the run-off equations (2), (C–2), or (C–2f) over the drainage area. To obtain any discharge equation which belongs to either of these classes, only one integration with respect to x is required. In the third class are placed those equations for which two integrations with respect to x were necessary. Equation (1) must be integrated over the proper portion of the drainage area, and one of the three run-off equations (2), (C–2), or (C–2f) must be integrated over the remainder of the drainage area. The flood crest always occurs on the range in which a discharge equation of this third class is applicable.

When z is expressed for a certain interval by equation (C–2), and for a later interval by equation (C–2f) after z_0 is replaced by κ/c, two cases arise, one when $\bar{t} > L/v$ and the other when $\bar{t} < L/v$. These two cases are somewhat analagous to those which arise according as the concentration time exceeds or is less than the duration of the rain. When $\bar{t} > L/v$ it will never be necessary to perform more than two integrations with respect to x to obtain an expression for the discharge. One integration must be made on equation (C–2) over the proper portion of the drainage area and the other on equation (C–2f) over the remainder, in each case taking account of the time required for water travel. When $\bar{t} < L/v$ it is necessary

over part of the range to perform three integrations with respect to x, one on equation (1), another on equation (C–2) and a third on equation (C–2f), each over the proper portion of the drainage area with due regard for the time required for water travel.

When $\bar{t} > L/v$ equations (9) and (6) require no change; equation (C–5) holds only on the range $t_0+L/v \leqq t \leqq t_0+\bar{t}$; a new equation, not here derived, applies on the range $t_0+\bar{t} \leqq t \leqq t_0+\bar{t}+L/v$; and equation (C–5f), after z_0 has been replaced by κ/c, applies on the range $t_0+\bar{t}+L/v \leqq t \leqq \infty$.

When $\bar{t} > L/v$ equation (B–6) holds only on the range $t_0 \leqq t \leqq \bar{t}+t_0$; equation (B–9) holds only on the range $t_0 \leqq t \leqq \bar{t}$; a new equation requiring three integrations with respect to x, applies on the range $t_0+\bar{t} \leqq t \leqq t_0+L/v$; another new equation applies on the range $t_0+L/v \leqq t \leqq t_0+L/v+\bar{t}$; and finally equation (C–5f), after z_0 has been replaced by κ/c, applies on the range $t_0+\bar{t}+L/v \leqq t \leqq \infty$.

Consider now the expressions for the maximum discharge. It can be shown that for each value of t the values of y given by equations (C–6) and (C–6f) respectively, are less than the corresponding value of y given by equation (B–6). Hence evaporation reduces the discharge, and it is obvious that this should be so. It readily follows that the maximum discharge as given by equations (C–8) and (C–8f), respectively, is less than the maximum discharge given by equation (B–8).

It was explained in the second article that equation (B–8) has a physical interpretation. Equation (C–8) has a similar interpretation. This physical explanation can be most simply stated when the rate of evaporation, $E(t')$, is constant; in this case the maximum discharge can be described as equal to the discharge in a steady state from that portion of the drainage area situated above the equal water travel line which corresponds to the distance water travels from the time the rain stops till the time of the flood crest, diminished by the volume of rate of evaporation from the remainder of the drainage area at the time of the crest. It is clear, in the light of the explanation previously given for equation (B–8), why the maximum discharge has this value. If the rate of evaporation is not constant, then the maximum discharge is equal to the discharge in a steady state from that portion of the drainage area situated above the equal water travel line which corresponds to the distance water travels from the time the rain stops till the time of the flood crest, diminished by the volume of rate of evaporation obtained by integrating the rate of evaporation over the remainder of the drainage area at the time of the crest diminished by the time required for water to flow to the gage from where it fell as rain.

In equation (C–8f), which gives an expression for the maximum discharge when the rate of evaporation is dependent on the amount of water remaining with the soil, we can replace $r(1-e^{-t_0/c})$ by z_0, and then replace $z_0 e^{-\frac{1}{c}(t^*-x/v)-\frac{1}{\kappa}\int_0^{t^*-x/v}\varepsilon(t')dt'}$ by $z(t^*-x/v)$. Then $cz(t^*-x/v)$ can be replaced by $\phi(t^*-x/v)$, which function represents the depth of water remaining with the soil. Finally $\frac{1}{\kappa}\phi(t^*-x/v)\varepsilon(t^*-x/v) = E(t^*=x/v)$. Hence equation (C–8f) admits of exactly the same physical explanation as equation (C–8).

The final topic to be considered is the effect of evaporation on the time of the flood crest. This effect is not at all as obvious as the effect of evaporation on the maximum discharge. It is not obvious whether the effect of evaporation is to advance or to retard the time of the flood crest.

The difference between equation (B–6) and equation (C–6) is

$$1/c\int_0^{t'v} W(x)e^{-\frac{1}{c}(t'-x/v)}\left[\int_0^{t'-x/v} E(t')e^{t'/c}dt'\right]dx$$

Since all functions in the integrand are positive, this expression is an increasing function of t. Hence we conclude that the effect of evaporation is to advance the time of the crest; that is to say, the crest comes sooner when evaporation takes place than it does when evaporation does not occur after the rain stops. However, from the form of equation (C–7) it is evident that evaporation does not affect the time of the flood crest by a large amount.

The difference between equation (B–6) and (C–6f) is:

$$r(1-e^{-t_0/c})\int_0^{t'v} W(x)e^{-\frac{1}{c}(t'-x/v)}\left(1-e^{-\frac{1}{\kappa}\int_0^{t'-x/v}\varepsilon(t')dt'}\right)dx.$$

This is an increasing function of t; hence whether the rate of evaporation is dependent or independent of the amount of water that remains with the soil, the effect of evaporation is to advance the time of the crest.

SECTION 4: THE DIURNAL VARIATION OF THE RATE OF RUN-OFF

It is well known that in moderately dry weather a rather pronounced diurnal variation is often observed in the discharge of very small streams. This diurnal variation obviously cannot be observed in very dry weather, since small streams then become dry, although undoubtedly the cause which brings about the variation is still present; the variation in streamflow may be present also when the streams are flowing at more than average stages (that is, in moderately wet weather), but if so its amplitude is not so great and hence the phenomenon is not easily observed, although again the cause undoubtedly is present. However, no diurnal variation is observed in the larger streams; and it is the object of this section to explain why this variation is absent in the larger streams, and to show that the effect of this factor can be neglected in forecasting the time and magnitude of flood crests.

It is evident that there must be a diurnal variation in the rate of evaporativity; however, it is clear from equation (C–2f), that regardless of how great the amplitude E (t') may be in the rate of evaporativity, there can be no variation whatever in the rate of run-off, z. Moreover, from equation (C–2) it is evident that no variation in the rate of evaporation, E (t'), however great, can cause any variation in the rate of run-off, z. Since a diurnal variation is actually observed in the rate of run-off it is obvious then that equations (C–2) and (C–2f) do not represent all the conditions which occur in Nature.

It seems plausible that in the case of soils not covered with vegetation, the only forces acting on the water in the soil are gravity, the molecular attraction of the soil particles for the water molecules, and the vapor tension due to air circulating between the soil particles. Under this condition it seems that the equations given in section 1 represent the rate of run-off with a reasonable degree of accuracy. When plants are present, however, there is an additional force to be considered. The transpiration of plants seems to be equivalent to a force on the soil

water opposite to that of gravity. This influence causes the diurnal surge or variation in the rate of run-off.

Take the usual expression for the amount of water remaining with the soil at time t',

$$A\phi(t')=AR-F(t_0)-A\int_0^{t'} z\,dt'-\int_0^{t'} AE(t')dt',$$

and in accordance with the second fundamental assumption replace $E(t')$ by $\frac{1}{\kappa}\phi(t')\varepsilon(t')$. If $\theta(t')$ represents the magnitude of the force acting opposite to gravity which transpiration causes at time t', then the third fundamental assumption can be expressed as

$$cz=\frac{k\phi(t')}{\theta(t')},$$

where k is a constant of proportionality, whence we have

$$\frac{Ac}{k}z\theta(t')=AR-F(t_0)-A\int^{t'} z\,dt'-\int_0^{t'}\frac{A}{k\kappa}cz\theta(t')\varepsilon(t')dt';$$

then by differentiating we have

$$\frac{Ac}{k}\theta(t')\frac{dz}{dt'}+\frac{Ac}{k}z\frac{d}{dt'}\theta(t')=-Az-a\frac{Ac}{k\kappa}\theta(t')\varepsilon(t'),$$

or on simplifying,

$$\frac{dz}{z}+\frac{d\theta(t')}{\theta(t')}dt'=-\frac{k\,dt'}{c\theta(t')}-\frac{1}{\kappa}\varepsilon(t')dt'$$

On integrating this last expression between the limits 0 and t' and then solving for z we get

$$z=z_0\frac{\theta(0)}{\theta(t')}e^{-\int_0^{t'}\left[\frac{k}{c\theta(t')}+\frac{1}{\kappa}\varepsilon(t')\right]dt'} \qquad (36)$$

It should be emphasized that z_0 in equation (36) is not given by $r(1-e^{-t_0/c})$ as it has been in all previous equations, but instead $z_0=\frac{k}{\theta(0)}r(1-e^{-t_0/c})$.

The function $\theta(t')$ is periodic in ordinary weather with a period of 1 day. As this function increases, the rate of run-off decreases, and vice versa. The rate of evaporativity $\varepsilon(t')$ may be, and usually is, periodic also, but its oscillations do not produce any variation in the rate of run-off.

To obtain an expression for the discharge, equation (36) is integrated over the drainage area with due regard to the time required for water to flow from where it fell as rain to the gage. This is done by replacing t' by $t'-x/v$ and integrating with respect to x between the proper limits. It is evident that the exponential in equation (36) does not change rapidly with a change in t'. Therefore if $\theta(t'-x_1/v)$ corresponds to (or, rather, equals) $\theta(t'-x_2/v)$, the times $t'-x_1/v$ and $t'-x_2/v$ differing by 1 day, then on integrating equation (36) between the limits x_1 and x_2, the periodicity disappears. As the velocity of the water is not very great when streams are low, the distance which water will travel in 1 day is not relatively great, and therefore the stream at the outlet of a drainage area of moderate length does not display a noticeable diurnal variation in its discharge. Moreover the other irregularities of the drainage area tend to mask this phenomenon.

SECTION 5: HYDROGRAPHS OF DISCHARGE

Three hydrographs of hypothetical conditions are here computed and shown in the figures. Each hydrograph represents the discharge with evaporation neglected as well as with evaporation considered. Obviously the lower branch of each curve represents the discharge corrected for evaporation.

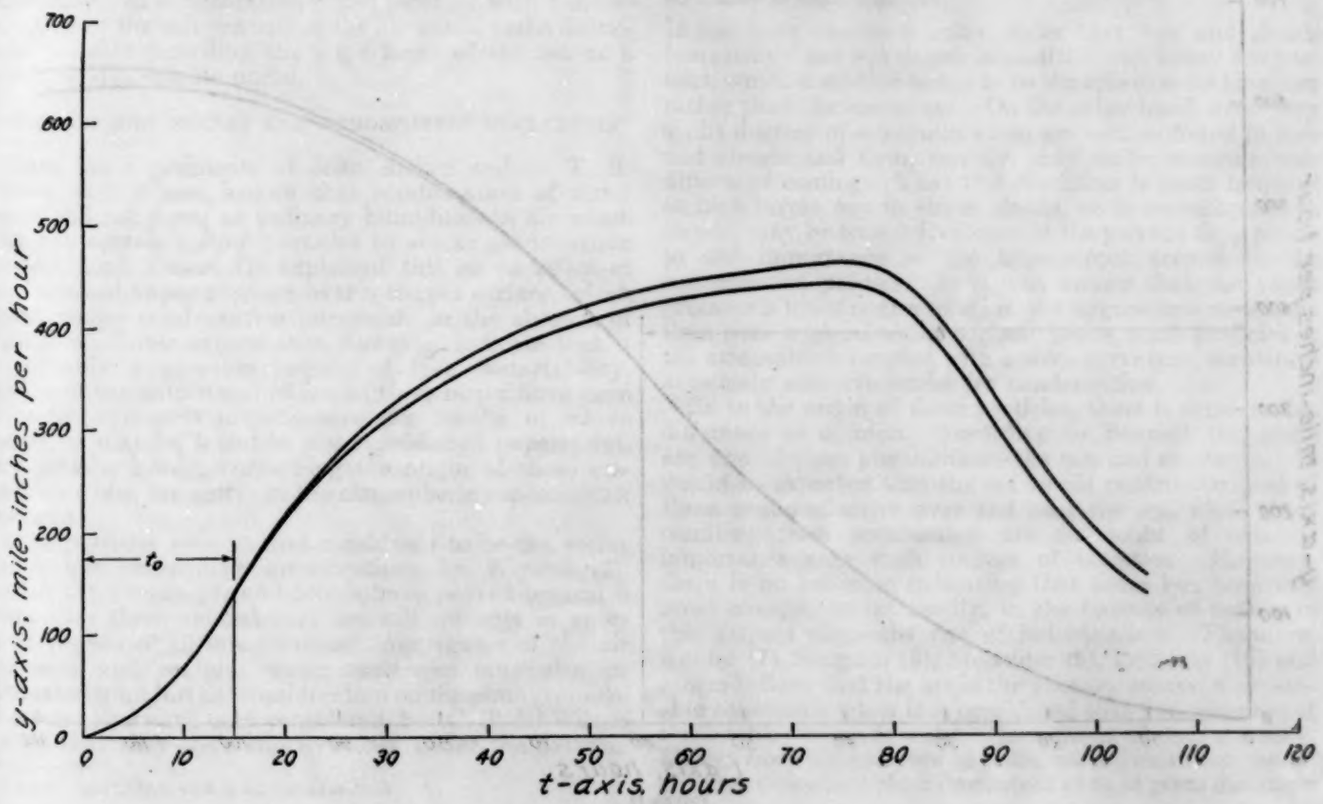

FIGURE 10.

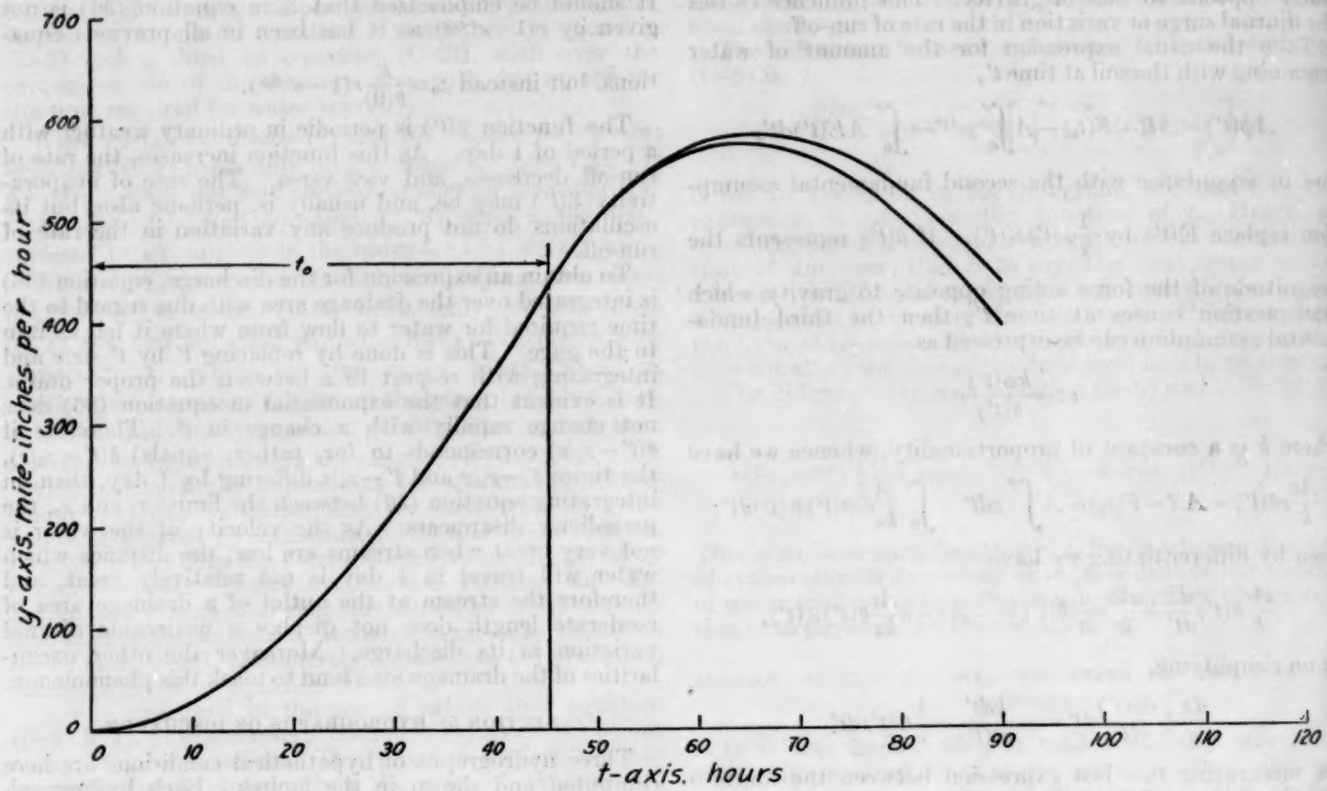

FIGURE 11.

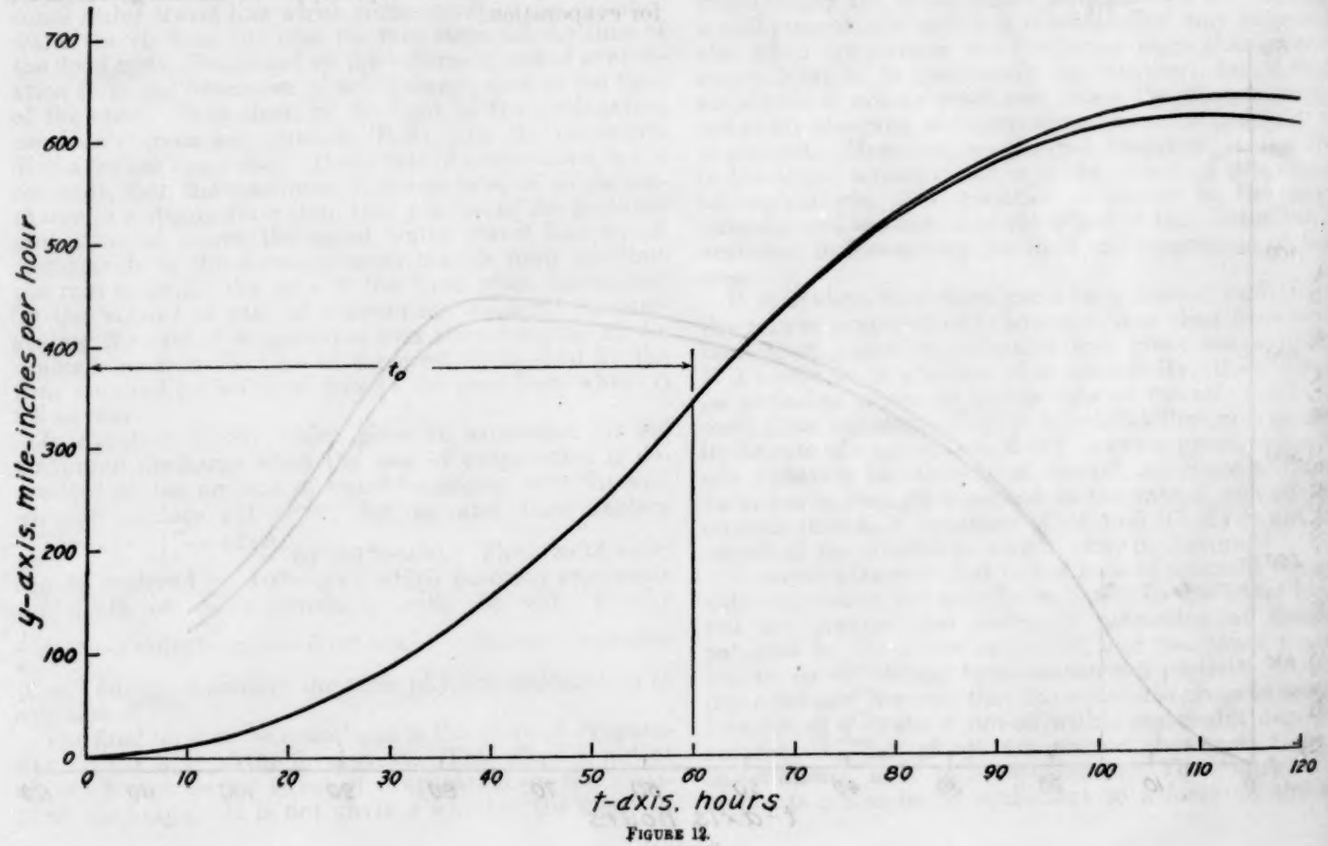

FIGURE 12.

Figure 10[3] shows the effect of evaporation on the discharge for a relatively short rain. For this figure the values of the constants are as follows: $t_0=15$ hours, $L=300$ miles, $W=40$ miles, $r=0.20$ inch per hour; $E=0.015$ inch per hour; $v=4$ miles per hour; $c=20$ hours; $t=20$ hours and $\varepsilon=0.015$ inch per hour. The values of E and ε are very high. Such high values are purposely assumed so as to form a conclusion of the maximum effect evaporation may have in diminishing the height of the crest. For this same reason W is purposely made large so that the time after the rain stops may be long during which evaporation may take place. The maximum discharge with evaporation neglected is 463.4 mile-inches per hour and 440.1 when corrected for evaporation. This is an extreme case and the effect of evaporation is only about 5 percent. In this case the effect of evaporation on the time of the crest is extremely minute.

Figure 11 was constructed from different values of the constants. In this case the values were purposely chosen to show the maximum effect evaporation may have on the time of the crest. For this figure $t_0=45$ hours, $L=180$ miles, $W=40$ miles, $r=0.15$ inch per hour, $E=0.015$ inch per hour, $v=4$ miles per hour; $c=40$ hours. It is further assumed that $\bar{t}>t_0+L/v$. When evaporation is neglected, the time of the crest is 65 hours 38 minutes from the beginning of the rain, and is 64 hours 9 minutes when evaporation is considered.

Figure 12 was constructed to show the effect of evaporation on discharge when there is no surface run-off. Here $c''=0$ and $c'=c=500$ hours, $t_0=$ 60 hours, $L=240$ miles, $W=200$ miles, $r=0.05$ inches per hour, $\varepsilon=0.005$ inches per hour, $v=4$ miles per hour. The effect of evaporation in this case is small also. Here the width of the drainage area has purposely been chosen 5 times as large as in the two earlier cases because of the scale in the figures.

[3] The figures are numbered consecutively with those in papers I and II.

PRELIMINARY REPORT ON A STUDY OF ATMOSPHERIC CHLORIDES

By WOODROW C. JACOBS

[University of California, Scripps Institution of Oceanography, La Jolla, Calif., August 1936]

An investigation of the salt [1] content of the air was begun at the Scripps Institution in January 1936. The primary purpose of the investigation, at the time it was initiated, was to attempt to prove that the formation of shallow haze or fog (salt haze), peculiar to coastal regions, is due to the presence of comparatively large salt particles or droplets of concentrated sea water suspended in the air. However, a later survey of the available literature in the field of colloid meteorology revealed that such an investigation might serve to fill a gap in our present knowledge of the sources of condensation nuclei. It was felt that a knowledge of the probable sizes of the particles and their effectiveness as condensation nuclei together with a determination of the salt content of the air would make deductions possible regarding the importance of the sea as a source of atmospheric nuclei.

CONDENSATION NUCLEI AND ATMOSPHERIC NUCLEATION

Since the experiments of John Aitken and C. T. R. Wilson, it has been known that condensation of water vapor will not occur at ordinary humidities in air which does not contain colloid particles to act as condensation nuclei. Lord Kelvin (1) explained this as an effect of the increased vapor pressure over a convex surface, which would render condensation impossible in the absence of a nucleus. Later experiments, however, indicate that it is probably a question largely of true metastability. Studies of the nature and effects of these nuclei have been made by numerous investigators, the results of whose researches may be found in many published papers; yet, very little is known concerning the origin of those suspensoids which are active in the atmospheric condensation processes.

Dust particles were at first considered to be the active nuclei; but subsequent investigations by Wigand (2), Boylan (3), Owens (4) and others have proved beyond a doubt that these neutral particles will act only at enormous degrees of supersaturation. Aggregates of the air molecules and complex water molecules may also be eliminated from further consideration on the same grounds. Molecular ions have been considered, but C. T. R. Wilson proved that they were effective only under the extreme conditions imposed within his cloud chamber. He found that to produce condensation on negative ions a relative humidity of 420 percent is required, on positive ions 790 percent. Appreciable supersaturation is necessary before condensation will take place on even those large, slow-moving, charged particles, the Langevin ions; therefore, it seems as though we may safely disregard these, too, as being effective in an atmosphere where such a state seldom exists. In fact, as stated by Willett (5):

> The whole trend at present, in the light of increasing observational data on the conditions actually prevailing in clouds where condensation is taking place, is to postulate an ever smaller degree of supersaturation in these processes.

It has been observed many times that fogs and clouds frequently form at relative humidities well below 100 percent, which condition seems to be the rule in some localities rather than the exception. On the other hand, even very slight degrees of supersaturation are seldom found in fogs and clouds and then, usually, only under extreme conditions of cooling. That this condition is more frequent at high levels, say in cirrus clouds, or in cumulo nimbus clouds, may be true. Evidence at the present time points to the importance of the hygroscopic aerosol in the condensation process. It is well known that the vapor pressure is lower over a solution or a hygroscopic substance than over a plane water surface, hence, such particles in the atmosphere, coupled with a large curvature, constitute extremely effective nuclei for condensation.

As to the origin of these particles, there is considerable difference of opinion. According to Bennett (6), there are two obvious possibilities—the sea and chimneys. It would be expected that the sea would contribute most of those nuclei effective over and near the sea, while those resulting from combustion are no doubt of extreme importance near such sources of pollution. However, there is no evidence indicating that there has been any great change, except locally, in the balance of nature in this respect since the rise of industrialism. Therefore, Köhler (7), Simpson (8), Melander (9), Ludeling (10) and others believe that the sea is the primary source; a reasonable conclusion when it is considered that five-sevenths of the earth's surface is water. In support of such a theory, Köhler from his analyses of rains, snows, and rime, found an almost constant chloride content even at great distances

[1] The term "salt", herein used, is not limited to *NaCl*.

from the sea, and also determined the presence of other salts in the same proportion as found in sea water. However, the results given by Riffenberg (11), from a survey of 200 published papers on analyses of rain water, do not indicate that this is true, but that the ratio of chlorides to sulphates, for instance, averages about 3 to 5. In spite of this evidence, nuclei counts made over the sea have invariably been of a small order, while similar counts in rural or urban areas have given comparatively large values. As suggested by Landsberg (12), there must be more chloride present in sea air than is indicated by condensation nuclei counts in such air.

APPARATUS AND METHOD OF ANALYSIS

No detailed description of the apparatus or of the procedure will be attempted here; it is expected that these important details will be fully described and illustrated in a later and more complete, report. In brief, however, the method of sampling consisted in passing a measured volume of air, reduced to a temperature of 0° C and a pressure of 760 mm, through a wash tower and filter; these served to remove all of the suspended matter and bring the salts into solution. The wash tower, itself, with a small sintered-glass filter fitted into the bottom (porosity 20 to 30 microns), was partially filled with chloride-free distilled water. After each run, which required from 6 to 12 hours, the liquid was carefully removed from the wash tower and the parts carefully washed. The contents, now about 500 cc, were then evaporated down to roughly 10 cc in order to increase the concentration of Cl. The amount of chloride present was determined by a titration method similar to that described by Riffenberg (13), with some changes due to the fact that such small quantities of the fluid to be analyzed were available. The titrations were made with a silver nitrate ($AgNO_3$) solution, potassium chromate (K_2CrO_4) being used as the indictor, and of such normality that 1 cc of the silver nitrate solution was equivalent to 0.1 mg of Cl. No doubt an electrometric method could have been used with success but it was desired to perfect a procedure which would not limit the analyses to sodium choride determinations.

The apparatus was mounted in the physics laboratory on the third floor of Ritter Hall, about 100 feet above sea level and only 200 feet away from the ocean high-tide mark; all collections were made at this point, the wash tower being mounted outside. During each run a complete record of the various meteorological elements was kept, such as wind speed and direction, pressure, temperature, humidity, total solar radiation, evaporation, visibility, state of the weather and sea, and air mass type. The data presented in table 1 are average values for the period of each collection. The series was made for the most part during May 1936, and consisted of 23 separate analyses. The period was characterized by a general lack of cyclonic activity which was rather unfortunate inasmuch as it was desired to correlate the variations in the chloride content of the air with changes in the various meteorological elements. Qualitative analyses made earlier in the year, under more extreme weather conditions, indicated higher chloride values than are shown by this series.

RESULTS OF THE ANALYSES

The analyses proved that there is considerable chloride present in the air and that the supply is continually being replenished from the sea. It is indicated, further, that a large proportion of the particles must be of such small size that they are capable of remaining suspended in the air. Except for an excess of chloride, which might occur with the presence of extremely large droplets or sea spray resulting from high on-shore winds, it is believed that the droplets of sea water are true colloidons and, as such, even without evaporation, may be considered as semi-permanent in the atmosphere. That is, they may remain suspended permanently unless removed through condensation and precipitation.

As illustrated in table 1, there is considerable variation in the chloride content of the various samples, the maximum content represented by sample number 4, is 0.518 milligrams of chloride per cubic meter of air; the minimum content, represented by sample number 5, is 0.076 mg per cubic meter. The average of the 23 analyses is 0.228 mg. These values would be equivalent to 0.854, 0.125, and 0.376 milligrams of sodium chloride (disregarding the magnesium chloride) per cubic meter of air respectively. As has just been suggested, these values are probably lower than would be found under more extreme weather conditions.

TABLE 1.—*Atmospheric chlorides*

Sample no.	Date	Cl	Wind		Humidity	Visibility
			Direction	Velocity		
	1936	*mg/m³*		*m/sec.*	*Percent*	
1	Apr. 28	0.247	SW	4.8	66	8
2	May 6	.142	SW	5.6	66	8
3	May 7	.340	NW	4.2	33	8
4	May 8	.518	W	4.1	42	8
5	May 8–9	.076	NW	1.1	51	8
6	May 10	.157	NW	2.6	82	6
7	May 11	.131	NE	2.4	81	6
8	do	.257	W	5.1	69	8
9	May 11–12	.278	SW	2.5	80	7
10	May 12	.267	W	4.0	62	8
11	do	.198	W	2.9	81	7
12	May 13	.102	NE	2.4	79	6
13	do	.250	NW	4.3	55	8
14	do	.186	N	1.9	75	8
15	May 14	.234	NW	3.4	75	8
16	do	.268	NW	6.0	61	9
17	do	.290	NW	2.5	85	8
18	May 15	.122	S	4.0	84	7
19	do	.407	SW	3.9	57	8
20	May 15–16	.146	SE	2.7	81	8
21	May 16	.340	S	5.7	67	7
22	do	.093	S	4.2	78	7
23	May 17	.194	SW	4.0	67	8
Average or mode.		.228	NW	3.7	68.6	8

In attempting to correlate the variation in the chloride content of the air with variations in wind speed and direction, relative humidity, visibility, etc., average conditions for periods of 6 to 12 hours had to be used. This method, in itself, tended to be a smoothing process, throwing most of the observations into several large divisions of each meteorological element and leaving only a few cases to represent the extreme conditions. Therefore, all elements illustrated in the several figures have been divided into a few large groups. In all cases, too much stress should not be placed on the extremes.

The most outstanding relationship is that of chloride content to wind velocity; as illustrated in figure 1, the chlorinity appears to vary directly as the wind velocity. There is also considerable variation in the amount of chloride with different wind directions; winds from the sea, of course, present the higher values. These data are represented graphically in figure 2.

A fair correlation between the chlorinity and relative humidity was found. The curve in figure 3 shows a decreasing chloride content with increase in humidity. This result seems reasonable when it is considered that a great many of the particles must be effective condensation nuclei, and as a result probably become nuclei of water

droplets at less than saturation values and thus settle out.

Many counts of condensation nuclei (*cf.* Landsberg, loc. cit.), have indicated a decrease in visibility with an increase in impurities; but an examination of figure 4 shows the opposite condition to be true here. Apparently these colloidons are not effective scattering agents.

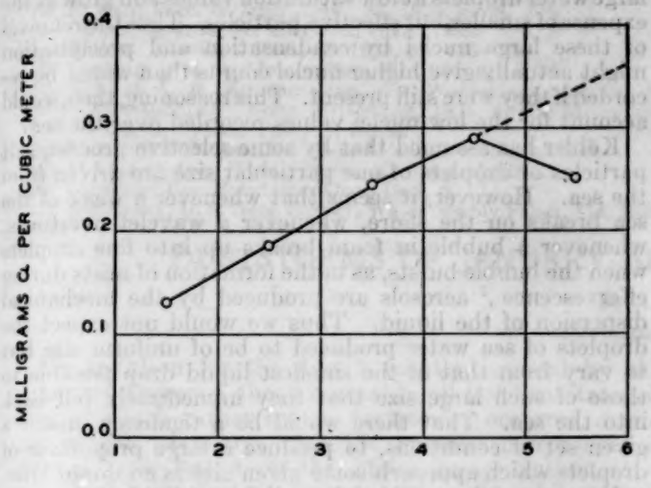

FIG. 1 WIND VELOCITY (M/SEC)

There appears to be considerable variation in the chloride content of the various air masses; but it would be expected that local influences at this seacoast location would tend to obliterate any actual variation that might

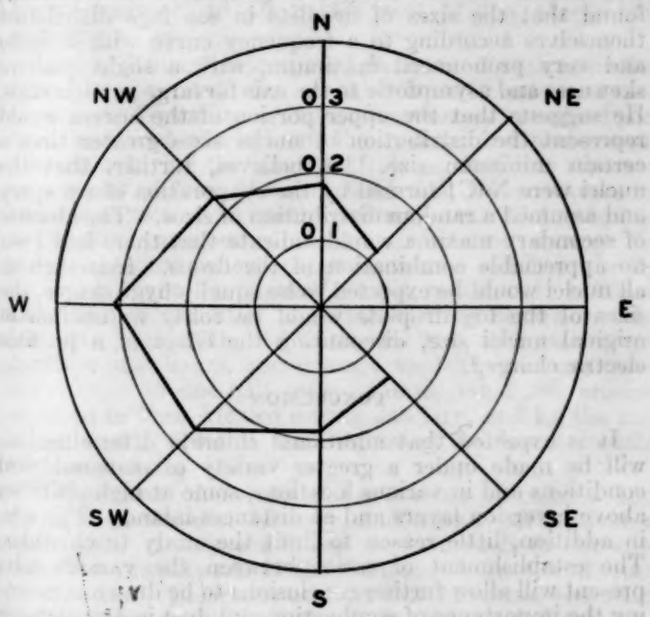

FIG. 2 WIND DIRECTION

exist unless a long series of observations were available. The present series is too short to determine much more than that maritime air masses, both fresh and transitional types, present higher chloride values than do those of continental origin. Ts (superior) air masses, in particular, presented low values, which agrees with the results of counts of condensation nuclei in air masses of high-level origin.

THEORETICAL CONSIDERATION OF THE DATA

When one considers that the ocean surface is constantly agitated by wind and waves, it is only logical to assume that much ocean water in the form of spray is temporarily suspended in the atmosphere. The surface tension of the small droplets causes them to evaporate and leave their salt content as suspensoids in the air. It is interesting

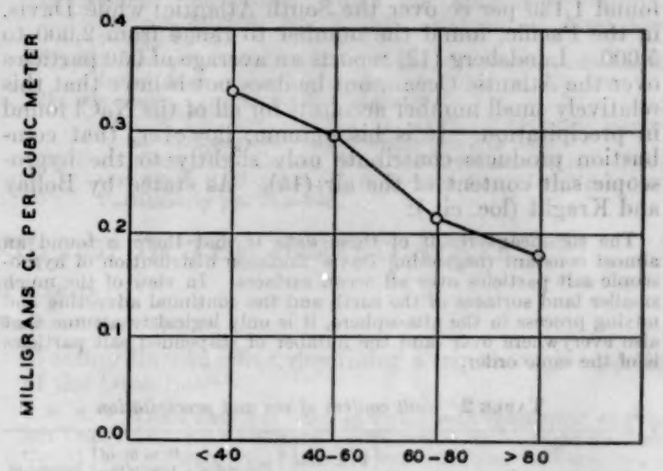

FIG. 3 RELATIVE HUMIDITY (%)

to consider that 0.1 mg of Cl, as collected, represents the chloride content of slightly more than 5 mg of sea water at normal chlorinity; or, more correctly, 0.1 mg of sea salt represents 2.86 mg of sea water at normal salinity. In other words, there would be a loss of nearly 30 times by weight before a salt crystal would be left. However, it is not suggested that these colloidons consist of minute

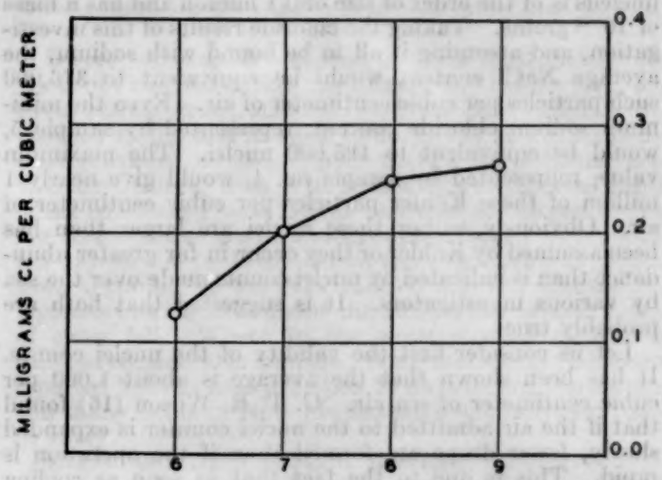

FIG. 4 VISIBILITY

crystals of sodium and magnesium chloride; in all probability they are most frequently small droplets of concentrated sea water. In any event, there is no reason to suppose that any one nucleus would be more highly hygroscopic than any other, for it would be expected that each would contain all of the salts found in sea water and in the same ratios. (See table 2.) Thus these nuclei would be more hygroscopic than pure NaCl because of the presence of $MgCl_2$, $MgSO_4$, and smaller quantities of

other highly soluble substances. Since the ocean surface of the earth far exceeds the land surface and the process of adding salt particles is a continuous one, it is not unreasonable that Köhler should find the ratios between the various salts of the ocean and precipitation similar.

Hess (14), in his counts of condensation nuclei, found an average of 1,060 nuclei per cubic centimeter of air over the North Sea and 800 over the Atlantic Ocean. Krocke found 1,130 per cc over the South Atlantic; while Davis, in the Pacific, found the number to range from 2,000 to 5,000. Landsberg (12) reports an average of 950 particles over the Atlantic Ocean, but he does not believe that this relatively small number accounts for all of the NaCl found in precipitation. It is his opinion, however, that combustion products contribute only slightly to the hygroscopic salt content of the air (15). As stated by Bollay and Kraght (loc. cit.):

> The significant result of these data is that there is found an almost constant (neglecting Davis' findings) distribution of hygroscopic salt particles over all ocean surfaces. In view of the much smaller land surfaces of the earth and the continual advecting and mixing process in the atmosphere, it is only logical to assume that also everywhere over land the number of suspended salt particles is of the same order.

TABLE 2.—*Salt content of sea and precipitation*

Salt	P. p. thsd. of sea water	Percent of total	P. p. m. of precipitation (Köhler)	Percent of total
$NaCl$	27.213	77.758	5.03	77.50
$MgCl_2$	3.807	10.875	.70	10.79
$MgSO_4$	1.658	4.737	.47	7.24
$CaSO_4$	1.260	3.600	.29	4.47
K_2SO_4	.863	2.465	----------	----------
$CaCO_3$	.123	.345	----------	----------
$MgBr_2$	.076	.217	----------	----------
Total	35.000	99.997	6.49	100.00

Köhler has computed that the average condensation nucleus is of the order of size of 0.1 micron and has a mass of 10^{-15} grams. Taking the chloride results of this investigation, and assuming it all to be bound with sodium, the average NaCl content would be equivalent to 376,000 such particles per cubic centimeter of air. Even the minimum sodium chloride content, represented by sample 5, would be equivalent to 125,000 nuclei. The maximum value, represented by sample no. 4, would give nearly 1 million of these Köhler particles per cubic centimeter of air. Obviously, either these nuclei are larger than has been assumed by Köhler or they occur in far greater abundance than is indicated by nuclei counts made over the sea by various investigators. It is suggested that both are probably true.

Let us consider first the validity of the nuclei counts. It has been shown that the average is about 1,000 per cubic centimeter of sea air. C. T. R. Wilson (16) found that if the air admitted to the nuclei counter is expanded slowly, fewer drops are formed than if the operation is rapid. This is due to the fact that as soon as cooling begins, condensation starts on some of the nuclei, with the result that some vapor is removed from the atmosphere and the final supersaturation is less than it would otherwise be. Bennett (6) concludes, therefore:

"* * * that all nuclei counted in the Aitken counter are not necessarily effective as condensation nuclei in the atmosphere, or, more correctly, some are far more effective than others."

A nuclei counter of the Aitken, or similar, type was not available for the study of this problem. However, at first analysis, without consideration of the mechanical details of the counter, it seems as though it would be just as possible to present Bennett's statement in the opposite fashion, e. g., the values given by the Aitken counter do not necessarily include all of the condensation nuclei effective in the atmosphere. Some particles may be so much more effective than others that they will become nuclei of large water droplets at low saturation values and grow at the expense of smaller, but effective, particles. Thus the removal of these large nuclei by condensation and precipitation might actually give higher nuclei counts than would be recorded if they were still present. This reasoning, then, would account for the low nuclei values recorded over the sea.

Köhler has assumed that by some selective process, salt particles or droplets of one particular size are driven from the sea. However, it seems that whenever a wave of the sea breaks on the shore, whenever a wavelet overturns, whenever a bubble in foam breaks up into fine droplets when the bubble bursts, as in the formation of mists during effervescence,[2] aerosols are produced by the mechanical dispersion of the liquid. Thus we would not expect the droplets of sea water produced to be of uniform size but to vary from that of the smallest liquid drop possible to those of such large size that they immediately fall back into the sea. That there would be a tendency, under a given set of conditions, to produce a large proportion of droplets which approach some given size is no doubt true.

Next we might consider the validity of Köhler's assumption as to the size of nuclei. When it is considered that it would take only 2.86×10^{-14} grams of sea water to produce a salt particle of the size assumed by Köhler, it is obvious that there is a great possibility for much larger particles to become suspended in the air and still be of true colloidal dimensions. H. G. Houghton (18), in a recent study, found that the sizes of droplets in sea fogs distributed themselves according to a frequency curve with a single and very pronounced maximum, with a slight positive skewness and asymptotic to the axis for large particle sizes. He suggests that the upper portion of the curves would represent the distribution of nuclei sizes greater than a certain minimum size. He believes, further, that the nuclei were NaCl formed by the evaporation of sea spray and assumed a random distribution of sizes. The absence of secondary maxima would indicate that there had been no appreciable combination of the drops. Inasmuch as all nuclei would be expected to be equally hygroscopic, the sizes of the fog droplets would be solely a function of original nuclei size, discounting the effect of a possible electric charge.[3]

CONCLUSION

It is expected that additional chloride determinations will be made under a greater variety of meteorological conditions and in various locations, some at high altitudes above inversion layers and at distances inland. There is, in addition, little reason to limit the study to chlorides. The establishment of ratios between the various salts present will allow further conclusions to be drawn concerning the importance of combustion and dust in atmospheric nucleation; and the accumulation of more data will allow many further problems to be considered at length.

As a final statement, the writer wishes to gratefully acknowledge the constant assistance and advice of Dr. R. H. Fleming of the Scripps Institution, without whose aid this study would never have been undertaken. He

[2] It has been shown by Stuhlman (17) that the number and size of the droplets is largely a function of bubble size.

[3] It has been shown, experimentally, that the charges on nuclei seldom exceed one electronic charge. A charge of plus or minus many times this number of electrons would be of infinitesimal importance in rendering the nucleus more hygroscopic.

wishes, further, to acknowledge the kindly interest and helpful suggestions of Dr. Geo. F. McEwen, S. W. Chambers, and Drs. D. L. Fox and C. E. Zobell, also of the Scripps Institution.

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DUSTSTORMS OF JANUARY–APRIL 1937 IN THE UNITED STATES

By R. J. MARTIN

[Weather Bureau, Washington, June 1937]

Precipitation for the first 3 months covered by this summary averaged above normal in all but five States, in four of which rather severe duststorms occurred during the period. January, with the greatest percentages of normal precipitation in the Plains States and most of the Dust Bowl, had the fewest duststorms, while March, with substantial to heavy precipitation in the Plains States, and much less than normal in most eastern sections, had the most extensive storms. April brought above-normal precipitation to the far Northwest, portions of the northern Great Plains, the middle and upper Mississippi Valleys, and, except for Arkansas, Louisiana, Mississippi, and Tennessee, to all States east of the ninety-fifth meridian.

During January, widespread dusty conditions prevailed over a large central area, reaching from Illinois westward to eastern Wyoming. These duststorms, mostly light, were scattered throughout the month, but were most numerous during the latter half; dense dust was reported in portions of New Mexico, Oklahoma, Texas, Colorado, and one or two other Southwestern States. Colorado had an unusual number of violent duststorms during the month in southeastern counties, where soil blew badly with only light to moderate wind movement; in Baca and Prowers Counties the storms were severe on the 5th, 13th, 15th, 17th, 23d, 27th, and 31st, with an average duration of 6 hours, and average visibility of from three city blocks to one-half mile. Considerable soil erosion occurred in New Mexico during January, and by the end of the month the soil was beginning to blow in southwestern Kansas.

The storms of February were more numerous and severe than those of January, and were reported over a wider area. Dusty conditions were noted from Brownsville, Tex., northward to the Canadian border, and from New Mexico, Colorado, and central Montana eastward to the Lake region and the Ohio Valley; aviators encountered dust clouds at elevations of 12,000 feet. Observations and computations made by Soil Conservation officials indicated that in one storm, Page County, Iowa, received 274 pounds of dust per acre, while at Sault Ste. Marie, Mich., the fall amounted to 11.65 tons per square mile; Drs. Hunt and Halverson, Northern State Teachers College, estimated the fall at Marquette, Mich., at 14.9 tons to the square mile.

The following extracts are from a letter written by A. E. Osborn, official in charge at the Dodge City, Kans., Weather Bureau office, describing a trip through a portion of the Dust Bowl:

> * * * Light dust was blowing with a southwest wind when we left Dodge City, with visibility a little over a mile. Light dust continued until we were about 10 miles north of Liberal (Kans.) where a dense dust cloud blew in from the north and brought visibility down to 15 or 20 feet at once. The driver experienced great difficulty in staying on the road. After an hour or more of this almost blind driving we arrived at Liberal at 7:10 a. m. We left Liberal for Hooker, Okla., at 7:20 a. m. The dust continued very thick and frequent stops were made because the visibility was practically zero. Three hours and forty-five minutes were required to drive the 23 miles. * * * The trip from Liberal, Kans., to Dalhart, Tex., was through part of the very worst section of the Dust Bowl. * * * Through this region there was very little evidence of any moisture in the soil. The topsoil was very dry and powdery and there was practically no moisture * * * for a depth of several feet. Finely powdered dust was in evidence everywhere, in drifts several feet high, depending upon the height of the object causing the drift. Deserted farm homes seemed to be the rule rather than the exception * * * (Feb. 17, 1937).

Severe soil erosion occurred in some southeastern districts of Colorado during this month, and most wheat, and even buffalo grass, suffered. On the 5th visibility was reduced to 100 feet in Baca County, and at Pueblo dense dust prevailed on the 7th for more than 2 hours; zero visibility, lasting from 7 to 10 hours, was reported south of the Arkansas-Platte Divide and east of the mountains. Air and highway traffic was disrupted from 7 to 20 hours per day on the 14–17th, and on the 15th dust was general from Wyoming to the New Mexico border. Kansas had vigorous storms until about the 20th, when several inches of snow fell. Wheat in the western third of Kansas suffered considerable damage. Some stations in Oklahoma reported light to heavy dust on 20 days during the month, and many fields in New Mexico were left ashy, dry, and powdery.

March and April brought the most extensive duststorms that have prevailed in recent months. In March light dust was reported, at the surface or aloft, from the Rocky Mountains eastward to the Atlantic coast, and from extreme southern Texas northward into Canada. Dense dust, however, occurred over nearly the same areas as in the preceding 2 months—portions of the northern and southern Great Plains, southward to Texas, and in the far Southwest.

The most severe storms of March occurred in Kansas, Oklahoma, Texas, New Mexico, and Colorado during the third week, and it was during and after this period that the Middle Atlantic and east Gulf States reported dust.

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At many eastern stations the clouds passed over, reducing ceiling, but not horizontal visibility. In the Dust Bowl visibility was often reduced to zero at the height of the storms, schools were closed, flying schedules canceled, and railway and highway traffic seriously impeded. Near Kingsdown, Kans., on the 25th, a train was delayed several hours while the crew shoveled a dustdrift from the track. Immeasurable damage was done to growing wheat and other crops by the flying sand, and over large areas grass on the southwestern ranges was covered with dust and made unfit for cattle.

Widespread, moderate to substantial rains or snows near the end of the month greatly alleviated, though only temporarily, the dusty conditions over much of the Plains area and the Southwest, leaving those sections in a more promising situation than for many months.

April brought decidedly more than normal precipitation to most eastern and northeastern States, and to limited portions of the northern Great Plains and the far Northwest, but a large western area, reaching from the Plains States westward to the Pacific Coast, received less than normal. Deficiencies were greatest in the southern Great Plains and the Southwest, with totals for the month ranging from 19 percent of normal in Arizona to 32 in Texas and up to 96 percent in Wyoming.

As a result of continued dryness, duststorms were again frequent, and dense dust was reported during the month from Texas and New Mexico northward to Montana and the Dakotas and from Colorado eastward to the Mississippi Valley, while light dust was noted from the Rocky Mountains eastward to the Atlantic Coast. The number of days on which dusty conditions were reported varied widely at different stations, ranging from, one at Hampton Roads, Va., to as many as 19 in portions of Kansas, while in New Mexico strong winds prevailed throughout the month, and local duststorms occurred in some sections of the State every day. At several Lake Region stations, chiefly in Wisconsin and Michigan, the presence of dust in the atmosphere was shown by deposits of mud following showers.

Dense dust was most frequent during the latter half of the month and the dusty conditions in the Atlantic area obtained near the close of April. Visibility during the storms ranged from zero to several miles; in numerous instances it was reduced to less than one mile for several hours—at Havre, Montana, zero visibility on the 13th lasted only 2 minutes, while at Amarillo, Texas, on the 23d the duration was 2 hours. On the 6–8th strong northwest winds in New Mexico caused one of the most severe duststorms of the season; dust on the 6th was confined to the extreme northeast corner of the State, but on the 7–8th it covered all sections between the Rio Grande River and the Colorado State line eastward and southward to Texas. Much damage was done to wheat and other crops in the central portion of this area. On the 28th visibility in northeastern New Mexico was reduced to 25 feet.

In South Dakota duststorms were more numerous than usual and were reported from all sections during the month, especially in the western portion; they were most damaging from the 24th to the 26th. In western Kansas duststorms were especially severe on the 2, 7, 11, 12, 14, 16, 17, 22, 24, and 25th, though all parts of that section were not affected on each of these days. In the southwestern counties the air was more or less filled with dust on from 15 to 19 days of the month and wheat was severely damaged. In Colorado a storm on the 27th made driving extremely dangerous and all air transportation was grounded due to poor visibility. Choun,[1] describing the duststorms in Colorado during the month, says that the storm on the 27th, which covered practically the entire State, was comparable in severity to any during the past 2 years. Travel was hazardous and automobiles were damaged by blowing sand; radio equipment in airplanes was rendered useless and many planes made forced landings due to this cause. A transport plane made a forced landing at Sterling, Colo., after 1,000 automobiles and some fire-fighting apparatus responded to an emergency alarm and lighted the airport with their headlights. The dustfall at Fort Collins, Colo., was estimated at 420 tons per square mile.

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SOLAR OBSERVATIONS

SOLAR OBSERVATIONS DURING APRIL 1937

By IRVING F. HAND, Assistant in Solar Radiation Investigations

For a description of instruments employed and their exposures, the reader is referred to the January 1935 REVIEW, page 24.

Table 1 shows that solar radiation intensities averaged above normal during April at Washington, Madison, and Blue Hill. The intensities at Lincoln averaged below normal, chiefly because of dust storms. On the afternoon of the 14th, although there were no condensed water-vapor clouds present, dust depleted radiation receipt to such a degree that the values at Lincoln are considerably less than 10 percent of those taken a week later. Observations taken through dust when other clouds are not present are included in the mean values because this is the simplest manner of determining the effect of dust storms in absorbing, scattering, and reflecting radiation from the sun and sky.

With the exception of three stations near the seacoasts, Fresno, New Orleans, and Riverside, all values of the total solar and sky radiation received on a horizontal surface at the other stations during April were below normal.

More turbidity measurements were made by the Weather Bureau during April than during any previous month.

Polarization observations made at Madison on 3 days give a mean of 58.0 percent with a maximum of 62 percent on the 13th. These are slightly below the corresponding normals for the month. No readings were made at Washington because the polarimeter had become defective.

TABLE 1.—*Solar radiation intensities during April 1937*

[Gram-calories per minute per square centimeter of normal surface]

WASHINGTON, D. C.

Date	Sun's zenith distance: 8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon	Local mean solar time
	75th mer. time	Air mass: A. M.				*1.0	P. M.					
	e	5.0	4.0	3.0	2.0		2.0	3.0	4.0	5.0	e	
	mm	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm*	
Apr. 12	3.45	0.83	0.94	1.07	1.27	1.50	1.18	1.00	------	------	3.00	
Apr. 14	7.87	------	------	------	.77	------	------	------	------	------	7.04	
Apr. 17	2.87	------	------	------	1.28	------	------	------	------	------	2.62	
Apr. 19	66.50	------	------	------	1.14	1.47	------	------	------	------	3.63	
Apr. 20	5.56	------	------	------	------	1.39	------	------	------	------	3.81	
Apr. 22	7.57	------	------	------	1.13	------	------	------	------	------	7.04	
Apr. 23	5.36	------	------	.82	.88	------	.98	------	------	------	6.02	
Apr. 30	7.57	------	------	.93	1.15	------	------	------	------	------	3.15	
Means	------	(.83)	(.94)	.94	1.09	1.45	(1.08)	(1.09)	------	------	------	
Departures	------	+.13	+.15	+.05	+.01	+.09	−.01	+.11	------	------	------	

MADISON, WIS.

Apr. 9	2.62	------	------	1.19	1.35	1.70	------	------	------	------	2.62	
Apr. 10	3.45	------	1.10	1.20	------	------	------	------	------	------	2.49	
Apr. 13	5.56	------	.97	1.13	1.32	1.70	------	------	------	------	4.57	
Apr. 19	4.75	------	------	1.03	1.27	------	------	------	------	------	3.99	
Apr. 22	4.17	------	------	1.17	1.31	1.52	------	------	------	------	4.75	
Means	------	------	(1.04)	1.14	1.31	1.64	------	------	------	------	------	
Departures	------	------	+.12	+.10	+.11	+.19	------	------	------	------	------	

*Extrapolated.

TABLE 1.—*Solar radiation intensities during April 1937*—Continued

LINCOLN, NEBR.

Date	Sun's zenith distance: 8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon	Local mean solar time
	75th mer. time	Air mass: A. M.				*1.0	P. M.					
	e	5.0	4.0	3.0	2.0		2.0	3.0	4.0	5.0	e	
Apr. 9	3.63	------	1.00	1.20	1.39	1.59	------	------	------	------	3.00	
Apr. 12	6.50	------	1.09	1.26	1.39	1.55	------	------	------	------	4.95	
Apr. 13	6.27	------	------	------	.54	------	------	------	------	------	4.57	
Apr. 14	5.56	------	------	------	------	------	------	0.09	0.07	0.05	6.27	
Apr. 19	4.56	0.81	.96	1.14	1.40	1.53	------	------	------	------	5.16	
Apr. 21	6.02	------	.89	1.00	1.24	1.48	1.26	1.02	.84	.69	5.56	
Apr. 22	7.57	------	------	.52	.90	------	1.06	------	------	------	5.94	
Apr. 30	6.27	------	.74	.80	1.10	1.52	------	------	------	------	7.29	
Means	------	(.81)	.94	.99	1.14	1.53	(1.16)	(1.56)	(.46)	(.37)	------	
Departures	------	+.10	+.11	+.02	−.05	+.08	.00	−.39	−.35	−.30	------	

BLUE HILL, MASS.

Apr. 1	1.8	------	------	1.15	1.37	1.42	1.15	1.00	0.77	------	1.8	
Apr. 4	3.6	------	0.89	1.02	1.20	1.41	------	------	------	------	3.2	
Apr. 7	4.2	------	------	------	------	1.40	1.03	.94	.84	0.75	3.7	
Apr. 11	3.6	------	------	------	1.19	1.41	------	------	------	------	3.4	
Apr. 12	3.8	------	------	------	1.27	1.42	------	------	------	------	3.8	
Apr. 13	3.5	------	------	------	------	1.42	1.26	------	------	------	3.3	
Apr. 14	5.8	------	------	------	1.03	1.32	------	------	------	------	4.6	
Apr. 17	2.9	------	------	------	1.30	1.43	------	------	------	------	2.8	
Apr. 19	5.8	------	------	------	1.04	1.29	1.14	1.01	.93	.86	4.8	
Apr. 20	3.6	------	------	1.14	1.27	1.43	1.16	.94	.76	------	4.0	
Apr. 24	3.3	------	------	1.05	1.29	1.48	1.28	1.20	1.05	.95	3.5	
Apr. 25	2.6	.95	1.03	1.24	1.27	1.41	------	------	------	------	2.4	
Apr. 26	3.0	------	------	1.15	1.29	1.46	1.16	1.00	------	------	2.3	
Apr. 30	5.2	------	------	------	1.28	1.48	1.29	1.18	1.08	------	2.5	
Means	------	(.95)	(.96)	1.12	1.23	1.41	1.19	1.04	.90	.85	------	
Departures	------	+.07	+.01	+.02	+.04	+.01	+.07	+.03	−.03	.00	------	

TABLE 2.—*Average daily totals of solar radiation (direct + diffuse) received on a horizontal surface*

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Fresno	Fairbanks	Twin Falls	La Jolla	Miami	New Orleans	Riverside	Blue Hill	San Juan	Friday Harbor	Ithaca
	Gram-calories per square centimeter															
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Apr. 2	332	277	326	170	260	516	281	399	509	420	467	510	265	494	312	276
Apr. 9	341	470	565	392	327	601	336	431	437	435	543	525	342	538	317	257
Apr. 16	509	379	525	333	383	676	306	525	570	486	505	580	383	643	320	272
Apr. 23	385	252	193	292	428	629	431	439	623	452	408	590	410	648	395	317
	Departures from weekly normals															
Apr. 2	−37	−150	−83	−119	−64	+4	−43	−32	------	−45	+94	+20	−93	------	+31	+1
Apr. 9	−49	+52	+114	+52	+10	+22	−47	−43	------	−41	+150	+21	−2	------	+4	−4
Apr. 16	+80	−35	+74	−1	+18	+77	−79	+55	------	+14	+86	+53	−38	------	−79	−37
Apr. 23	−62	−197	−245	−60	+49	+49	+27	−65	------	−26	+24	+74	−52	------	−98	−37
	Accumulated departures on Apr. 29															
	−3,101	−1,267	−2,611	+7	+1,561	+1,715	−581	−1,260	------	−2,702	−3,605	−511	−3,283	------	+875	+833

TABLE 3.—*Total, I_m, and screened, I_y, I_r, solar radiation intensity measurements, obtained during April 1937, and determinations of the atmospheric turbidity factor, β, and water-vapor content, w=depth in millimeters, if precipitated*

AMERICAN UNIVERSITY, WASHINGTON, D. C.

Date and hour angle	Solar altitude	Air mass	I_m	I_y	I_r	$\beta_{I_{y-r}}$	$\beta_{I_{y-r}}$	β_{m-vis}	$\frac{I_{w-v}}{1.94}$ Percentage of solar constant	$\frac{I_{w-v}-I_m}{1.94}$ Percentage of solar constant	w	Air-mass type	Temperature	Wind
1937	° ′	m	gr. cal.	gr. cal.	gr. cal.						mm			
Apr. 12:														
0:52 p. m.	57 39	1.18	1.435	1.034	0.822	0.069	0.032	0.050	82.3	8.1	4.8	N_{rc}	5° C.	N-10.
0:56 p. m.	57 19	1.19	1.452	1.032	.820	.054	.031	.042	84.0	8.9	6.2			
3:59 p. m.	28 51	2.07	1.182	.872	.705	.066	.060	.063	71.0	9.9	7.9			
4:02 p. m.	29 18	2.10	1.167	.870	.705	.058	.066	.067	70.5	10.1	8.1			
4:27 p. m.	23 31	2.50	1.096	.806	.672	.070	.086	.078	63.3	6.6	2.3			
4:31 p. m.	22 44	2.58	1.063	.804	.675	.079	.089	.084	61.4	6.4	2.1			
Apr. 14:														
4:24 a. m.	24 33	2.40	.671	.489	.392	.141	.159	.150	51.1	16.4	34.8	$N_r \rightarrow T_s$	10° C.	SW-8.
4:19 a. m.	25 30	2.32	.684	.486	.390	.138	.164	.151	51.8	16.[illegible]	35.2			
3:58 a. m.	29 30	2.02	.763	.550	.442	.146	.182	.164	53.8	14.3	34.0			
3:54 a. m.	30 18	1.98	.777	.552	.444	.142	.178	.160	54.1	13.9	31.8			
Apr. 17:														
4:11 a. m.	27 42	2.14	1.252	.933	.750	.046	.034	.040	73.9	8.8	4.3	P_c	7° C.	SE-6.
4:08 a. m.	28 16	2.10	1.247	.935	.752	.052	.037	.044	74.1	9.3	5.0			
3:00 a. m.	40 57	1.53	1.367	.982	.785	.046	.046	.046	79.2	8.2	4.0			
2:58 a. m.	41 19	1.51	1.367	.985	.787	.048	.046	.047	79.2	8.2	4.0			
Apr. 19:														
3:10 a. m.	39 39	1.57	1.230	.916	.738	.094	.074	.084	72.2	8.3	4.0	N_{rc}	6° C.	NW-10.
3:04 a. m.	40 42	1.53	1.252	.919	.740	.087	.077	.082	73.6	8.5	4.2			
2:42 a. m.	44 37	1.42	1.270	.938	.754	.095	.075	.085	74.2	8.2	4.0			
2:39 a. m.	45 08	1.41	1.281	.940	.757	.090	.076	.083	74.2	7.7	3.8			
2:08 a. m.	50 17	1.30	1.327	.980	.783	.090	.060	.075	77.3	8.4	4.8			
2:05 a. m.	50 47	1.29	1.335	.982	.785	.086	.062	.074	77.2	7.8	4.0			
1:01 a. m.	59 10	1.17	1.405	.994	.794	.066	.064	.065	81.4	8.4	5.1			
0:58 a. m.	59 26	1.16	1.368	.996	.797	.090	.066	.078	78.6	7.5	3.9			
1:11 p. m.	58 07	1.18	1.351	.968	.764	.078	.051	.064	80.4	10.1	10.4			
1:14 p. m.	57 48	1.18	1.353	.971	.766	.081	.053	.067	80.2	9.8	10.0			
2:09 p. m.	50 07	1.30	1.295	.973	.736	.078	.058	.068	78.6	11.2	17.0			
2:12 p. m.	49 39	1.31	1.300	.931	.736	.064	.060	.062	78.8	10.7	15.0			
Apr. 20:														
3:24 p. m.	37 07	1.65	1.053	.787	.658	.150	1.66	.158	60.0	5.2	1.7	N_{rc}	7° C.	NW-9.
3:30 p. m.	36 00	1.70	1.014	.783	.653	.170	1.50	.160	59.0	6.2	2.1			
Apr. 22:														
4:09 a. m.	29 10	2.05	1.119	.858	.686	.082	.056	069	69.6	11.4	14.0	N_r	3° C.	N-12.
4:06 a. m.	29 44	2.01	1.135	.860	.689	.082	.060	.071	69.2	10.2	8.0			
3:02 a. m.	41 46	1.50	1.183	.891	.707	.112	.068	.090	71.6	10.1	9.9			
2:58 a. m.	42 29	1.48	1.191	.893	.712	.112	.072	.092	72.0	10.1	9.9			
2:40 a. m.	46 01	1.39	1.230	.884	.731	.108	.150	.129	68.7	4.7	1.6			
2:33 a. m.	46 54	1.37	1.162	.886	.731	.170	.150	.160	65.0	4.6	1.6			
Apr. 23:														
5:03 a. m.	18 52	3.07	.799	.677	.564	.142	.088	.115	52.6	10.9	8.1	P_c	4°C.	SE-6.
5:01 a. m.	19 17	3.00	.803	.682	.571	.136	.092	.114	52.0	9.1	5.0			
4:13 a. m.	28 36	2.08	.852	.674	.550	.186	.140	.163	53.5	9.6	6.4			
4:10 a. m.	29 05	2.06	.870	.766	.637	.154	.142	.148	55.7	10.4	8.6			
Apr. 30:														
4:48 a. m.	23 08	2.54	.994	.806	.651	.108	.058	.082	62.5	10.7	8.8	N_{rc}	5° C.	SE-7.
4:43 a. m.	24 05	2.44	1.052	.806	.651	.078	.068	.073	64.8	10.1	7.2			
1:03 a. m.	62 11	1.13	1.445	.996	.799	.046	.072	.059	81.8	6.6	3.0			
1:00 a. m.	62 31	1.12	1.400	.996	.799	.078	.074	.076	79.6	6.8	3.1			

BLUE HILL METEOROLOGICAL OBSERVATORY OF HARVARD UNIVERSITY

Date and angle hour (1937)	Solar altitude	Air mass	I_m	I_y	I_r	$\frac{I_y}{.889+C}$	$\frac{I_r}{.878+C}$	β mean	$\frac{I_{w-v}}{1.94}$ Percentage of solar constant	$\frac{I_{w-v}-I_m}{1.94}$ Percentage of solar constant	w	Air-mass type
Apr. 1	° ′	m	gr. cal.	gr. cal.	gr. cal.	gr. cal.	gr. cal.				mm	
4:19 a. m.	21 14	2.75	1.176	0.789	0.649	0.925	0.773	0.048	67.0	6.3	3.8	N_{rc}
2:45 a. m.	41 23	1.52	1.292	.845	.681	.983	.803	.072	73.9	7.2	5.9	
0:18 p. m.	51 35	1.22	1.375	.885	.707	1.022	.834	.070	58.0	6.9	6.3	
2:35 p. m.	28 38	1.60	1.215	.805	.646	.945	.771	.063	70.0	7.2	5.6	
4:35 p. m.	14 57	3.80	.797	.578	.478	.678	.570	.071	55.3	17.2	8.9	
Apr. 4												
4:09 a. m.	24 34	2.39	.889	.618	.543	.724	.571	.062	67.0	22.2	14.5	N_{rc}
Apr. 7												
4:32 a. m.	20 31	3.84	.964	.683	.562	.913	.668	.026	65.0	15.0	7.7	P_c
Apr. 11												
8:30 a. m.	34 30	1.76	1.272	.852	.693	.995	.826	.076	71.8	6.2	4.7	P_c
Apr. 12												
3:25 a. m.	32 00	1.88	1.283	.834	.677	.978	.805	.057	74.7	8.6	6.3	P_c
0:22 a. m.	55 32	1.21	1.392	.886	.714	1.037	.849	.075	78.7	6.9	6.3	
Apr. 13												
0:09 p. m.	56 43	1.19	1.419	.897	.826	1.035	.860	.086	76.6	5.5	6.0	N_{rc}
Apr. 14												
3:20 a. m.	35 53	1.70	1.059	.682	.560	.800	.667	.128	61.7	7.4	5.4	N_{rc}
Apr. 17												
3:26 a. m.	34 45	1.75	1.335	.866	.672	1.014	.799	.037	78.9	10.1	7.7	P_c
1:00 p. m.	55 55	1.20	1.453	.908	.714	1.064	.849	.046	82.9	8.0	7.1	
Apr. 19												
3:22 a. m.	35 33	1.72	1.106	.726	.596	.852	.709	.115	64.5	7.5	5.8	N_{rc}

TABLE 3.—*Total, I_m, and screened, I_y, I_r, solar radiation intensity measurements, obtained during April 1937, and determinations of the atmospheric turbidity factor, β, and water-vapor content, w=depth in millimeters, if precipitated*—Continued

BLUE HILL METEOROLOGICAL OBSERVATORY OF HARVARD UNIVERSITY—Continued

Date and angle hour (1937)	Solar altitude	Air mass	I_m	I_y	I_r	$\frac{I_y}{.889+C}$	$\frac{I_r}{.578+C}$	β mean	$\frac{I_{m,\lambda}}{1.94}$ (Percentage of solar constant)	$\frac{I_{m,\lambda}-I_m}{1.94}$ (Percentage of solar constant)	w	Air-mass type
Apr. 20	° ′	m	gr. cal.	gr. cal.	gr. cal.	gr. cal.	gr. cal.				mm	
3:17 a. m.	37 20	1.65	1.309	0.830	0.644	0.930	0.766	0.064	73.8	6.3	4.9	N_{PC}
1:36 a. m.	52 26	1.26	1.390	.874	.696	.985	.793	.055	77.9	6.8	6.1	
2:45 p. m.	42 51	1.47	1.341	.850	.672	.945	.759	.065	76.5	7.4	6.2	
Apr. 24												
3:38 a. m.	38 10	1.61	1.297	.858	.694	.965	.782	.065	75.0	8.1	6.4	P_A
1:05 a. m.	58 00	1.18	1.432	.930	.740	1.046	.843	.060	81.4	7.6	6.9	
3:07 p. m.	39 50	1.56	1.381	.880	.720	.991	.807	.044	77.5	6.3	5.1	
Apr. 25												
4:46 a. m.	22 10	2.63	1.025	.706	.579	.794	.650	.070	69.0	2.7	1.7	P_A
0:14 p. m.	60 35	1.14	1.385	.880	.716	.890	.815	.092	75.7	4.3	4.1	
Apr. 26												
3:52 a. m.	32 20	1.87	1.281	.854	.694	.961	.790	.076	59.0	7.0	5.2	P_A
0:14 p. m.	60 46	1.14	1.436	.914	.722	1.028	.822	.043	83.0	9.0	8.6	
2:59 p. m.	41 34	1.50	1.326	.858	.678	.965	.772	.065	76.0	8.0	5.4	
Apr. 30												
4:26 a. m.	26 51	2.21	1.165	.790	.638	.889	.727	.054	69.6	9.4	6.4	P_A
1:09 a. m.	58 25	1.18	1.420	.900	.714	1.001	.813	.059	81.0	7.8	7.2	
1:45 p. m.	54 08	1.24	1.397	.878	.702	.988	.800	.059	80.0	7.0	6.3	
4:39 p. m.	24 34	2.39	1.257	.706	.567	.794	.646	.062	68.1	3.3	2.2	
Mar. 1												
2:59 a. m.	20 44	2.22	1.302	.902	.685	.004	.012	.008	74.0	6.9	4.4	P_C
1:44 a. m.	34 54	1.74	1.413	.921	.775	.022	.083	.052	76.0	4.4	3.1	
0:11 p. m.	40 41	1.53	1.417	.903	.734	.030	.085	.058	78.4	6.5	5.5	
2:16 p. m.	31 24	1.92	1.318	.851	.687	.095	.099	.097	70.8	4.3	2.9	
3:17 p. m.	23 05	2.54	1.121	.760	.624	.088	.056	.072	68.5	11.7	7.2	
Mar. 2												
3:32 a. m.	20 59	2.77	.925	.649	.543	.062	.125	.094	48.0	2.7	1.6	P_C
0:48 a. m.	39 23	1.57	1.101	.734	.615	.058	.056	.057	79.0	13.3	10.5	
Mar. 3												
3:39 a. m.	20 10	2.88	1.200	.801	.655	.090	.054	.072	65.1	4.2	2.5	P_C
1:07 a. m.	38 39	1.60	1.421	.913	.733	.020	.047	.034	77.2	5.2	3.9	
1:10 p. m.	36 21	1.69	1.445	.927	.744	.030	.069	.050	76.0	2.8	1.9	
2:57 p. m.	25 41	2.30	1.316	.881	.701	.013	.035	.024	79.8	12.6	5.5	
Mar. 7												
3:14 a. m.	25 16	2.33	1.413	.937	.769	.020	.008	.014	81.2	10.0	6.5	P_C
1:48 a. m.	36 21	1.66	1.509	.938	.782	.023	.024	.024	81.3	4.7	3.5	
2:26 p. m.	23 23	2.51	1.401	.957	.758	.000	.013	.006	82.7	8.5	5.1	
Mar. 10												
3:03 a. m.	27 55	2.55	1.362	.915	.752	.005	.049	.027	76.0	6.5	3.1	P_C
Mar. 11												
2:31 a. m.	28 40	2.08	1.072	.754	.612	.078	.108	.093	65.7	8.7	5.9	P_C
Mar. 12												
2:26 p. m.	33 46	1.79	1.143	.637	.570	.078	----------	.078	65.7	12.7	9.9	P_C
Mar. 18												
2:35 a. m.	41 37	1.50	1.139	.780	.606	.018	.058	.038	82.5	24.3	20.0	P_C+P_A
Mar. 19												
3:37 a. m.	25 20	2.33	1.207	.774	.635	.023	.086	.054	70.0	11.1	7.3	P_C+P_A
Mar. 20												
3:36 a. m.	25 39	2.23	1.151	.768	.629	.025	.099	.062	71.7	12.8	8.4	P_C+P_A
Mar. 22												
3:20 a. m.	28 11	2.11	1.258	.850	.703	.034	.082	.058	70.0	5.5	3.6	P_C
0:32 a. m.	47 42	1.36	1.445	.925	.742	.056	.046	.051	80.0	5.9	4.9	
2:32 p. m.	35 52	1.70	1.371	.889	.719	.142	.007	.074	71.8	1.1	.6	
4:34 p. m.	15 48	3.63	1.008	.715	.576	.035	.051	.043	61.2	9.6	4.9	
Mar. 23												
3:29 a. m.	27 58	2.12	1.235	.818	.681	.042	.062	.052	72.5	9.3	7.2	P_C
Mar. 24												
4:52 a. m.	22 42	2.58	1.275	.808	.665	.040	.073	.056	67.5	7.3	5.5	P_C
3:08 a. m.	31 25	1.95	1.282	.842	.691	.068	.101	.084	67.0	1.9	1.2	
0:42 a. m.	48 07	1.34	1.398	.873	.715	.030	.091	.060	79.6	8.2	6.9	
Mar. 26												
3:21 a. m.	25 51	2.29	1.147	.746	.611	.042	.098	.050	72.0	11.8	7.7	P_C
0:50 a. m.	48 27	1.32	1.393	.875	.716	.082	.029	.056	80.0	8.6	7.3	
Mar. 27												
3:30 a. m.	28 54	2.06	1.290	.854	.699	.055	.075	.065	70.4	3.9	2.2	P_C
Mar. 28												
3:18 p. m.	31 02	1.94	1.314	.856	.689	.018	.056	.037	79.8	12.2	8.8	P_C
4:44 p. m.	16 45	3.45	1.143	.778	.635	.013	.054	.034	71.1	12.4	6.6	
Mar. 29												
3:26 a. m.	30 00	2.00	1.286	.844	.675	.021	.057	.039	76.5	10.3	7.1	P_C
1:31 a. m.	46 11	1.39	1.413	.899	.715	.056	.100	.078	84.0	11.3	9.4	
1:54 p. m.	43 36	1.45	1.417	.893	.703	.020	.030	.025	84.5	11.5	9.4	
4:55 p. m.	14 17	3.94	.992	.699	.562	.024	.038	.031	66.0	8.6	4.2	
Mar. 30												
3:28 a. m.	30 03	2.00	1.330	.875	.715	.048	.024	.036	72.0	3.5	2.8	P_C
0:41 a. m.	50 30	1.29	1.461	.933	.746	.023	.074	.048	82.4	7.1	6.1	
2:22 p. m.	39 59	1.55	1.413	.913	.725	.050	.012	.031	71.9	5.7	4.4	
5:02 p. m.	13 16	4.28	.961	.685	.560	.046	.026	.036	62.5	7.2	3.4	
Mar. 31												
0:23 a. m.	52 34	1.26	1.358	.873	.696	.044	.092	.068	79.0	9.1	7.9	P_C
2:29 p. m.	40 13	1.55	1.286	.828	.655	.069	.098	.084	72.0	5.8	4.3	
3:32 p. m.	29 53	2.00	1.112	.754	.603	.062	.098	.080	67.7	10.4	7.2	

Meteorological conditions during solar observations, Blue Hill, Mass.

Date	Time from local noon	Temperature °C.	Wind Beaufort	Visibility	Blue sky	Cloudiness and remarks
Apr. 1	4.20 a.m.	0.3	WNW 3	7	7	Few Ci; moderate haze.
1	2.17 a.m.	3.3	NNW 3	9	8	Few Ci; light haze.
1	0.16 p.m.	7.3	NW 3	9	8	Few Ci; few Cu.
1	2.34 p.m.	8.6	W 3	9	8	2 Cu; light haze.
1	4.52 p.m.	8.8	NW 3	9	8	Trace Ci; trace Cu; light haze.
4	4.17 a.m.	1.7	NW 2	6	7	3 Ci; few Acu; few Cu; moderate, dense haze.
7	4.34 p.m.	9.4	NW 3	8	7	2 Ci; light haze.
11	3.18 a.m.	1.8	NW 3	9	7	1 Acu; few Stcu; light haze to north.
11*	3.08 a.m.	3.1	NW 3	9	7	1 Acu; 1 Cu; stcu, light haze to north, instrument indoors.
12	3.27 a.m.	4.5	NW 3	8	8	1 Acu; few Cu; moderate haze to north.
12	0.24 a.m.	7.8	NNW 3	8	8	5 Cu; light haze to north, west, and south.
12	2.35 p.m.	7.9	NE 2	9	8	9 stcu; light haze to north.
13	0.06 p.m.	13.3	WSW 3	9	8	2 Ci; light haze.
14	3.23 a.m.	10.1	S 3	7	8	2 Ci; moderate haze.
17	3.33 a.m.	4.0	NNE 4	9	7	Zero clouds, light haze.
17*	1.22 a.m.	4.7	NNE 5	9	7	Do.
17	1.03 a.m.	4.3	NNE 5	9	7	1 Ci; trace Acu; light haze.
19	3.27 a.m.	10.0	NW 5	7	7	Zero clouds, moderate water haze.
19	0.16 a.m.	13.1	NW 3	8	7	4 Cu; moderate water haze.
19	1.57 p.m.	15.8	NW 2	8	7	1 Cu; moderate haze.
20	3.15 a.m.	9.6	NW 5	9	7	Trace Cu; light haze.
20	1.34 a.m.	11.6	WNW 5	9+	7	1 Cu.
20	2.31 p.m.	14.0	W 6	9+	7	2 Cu.
24	3.41 a.m.	2.9	NNE 5	8	8	Zero clouds moderate haze to north and west.
24*	1.48 a.m.	3.9	NNE 4	8	8	Trace Cu; light haze.
24	1.07 a.m.	3.4	NNE 4	9	8	Trace Cu.
24	3.05 p.m.	4.8	NNE 4	9	8	
25	4.58 a.m.	2.8	NW 3	8	8	1 Ci.
25	0.02 a.m.	9.6	NNE 3	9	8	3 Ci.
26	3.56 a.m.	8.5	E 3	8	8	Trace Ci; moderate haze to north and west.
26	0.08 p.m.	9.6	NE 4	9	8	1 Ci; moderate haze to north and west.
26	2.55 p.m.	7.7	NE 5	9	8	2 Ci; light haze.
60	4.28 a.m.	5.9	NNE 5	8	8	Zero clouds, light haze.
30	1.11 a.m.	8.3	NNE 3	9	7	Light haze.
30	1.43 p.m.	9.5	NNE 4	9	7	Do.
30	4.37 p.m.	10.6	NE 3	10	7	Light haze to north.

POSITIONS AND AREAS OF SUN SPOTS

NOTE.—The data for April 1937 will be published in the next issue of the Review.—Editor.

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR APRIL 1937

[Dependent alone on observations at Zurich and its station at Arosa]

[Furnished through the courtesy of Prof. W. Brunner, Eidgen. Sternwarte, Zurich, Switzerland]

April 1937	Relative numbers	April 1937	Relative numbers	April 1937	Relative numbers
1	*Mc* 140	11	*Ec* 82	21	*a* 127
2	128	12	62	22	*Mbbc* —
3	*d* 112	13	38	23	*b* 144
4	*Ec* 139	14	—	24	*Mbc* 157
5	*Ec* 149	15	*Eacd* —	25	*MEaac* 190
6	114	16	64	26	157
7	*Mc* 121	17	*a* 63	27	161
8	96	18	*Ec* 76	28	149
9	*ab* 86	19	*Ec* 94	29	*bd* 123
10	71	20	*Ec* 127	30	*b* 94

Mean, 27 days=113.5.

a=Passage of an average-sized group through the central meridian.
b=Passage of a large group or spot through the central meridian.
c=New formation of a group developing into a middle-sized or large center of activity: E, on the eastern part of the sun's disk; W, on the western part; M, in the central circle zone.
d=Entrance of a large or average-sized center of activity on the east limb.

AEROLOGICAL OBSERVATIONS

[Aerological Division, D. M. LITTLE, in charge]

By L. P. HARRISON

Mean free-air data based on airplane weather observations during the month of April 1937 are given in tables 1 to 3. A description of the methods by which the various monthly means and normals herein are computed may be found in this section of the MONTHLY WEATHER REVIEW of January and March 1937.

It will be noted that many of the "normals" are based on only 3 years of observations. Conclusions based on departures from such short-period "normals" must be used with caution.

The mean surface and free-air temperatures for April (see chart I and table 1) were practically normal over the entire country. Departures from normal were generally within the limits ±1° C. At a few isolated stations, however, limits of ±2° C. were reached.

The mean free-air relative humidities and specific humidities are given in table 2. Generally speaking, with the exclusion of the surface layer, several hundred meters in height, the mean relative humidities were slightly below normal in the southern half of the country (south of lat. 40°), except along the Pacific coast where they were mostly in excess of normal, and slightly above normal in the northern half of the country, except near Billings, where the opposite condition prevailed. The most pronounced negative departures from normal occurred over the vicinity of Pensacola, Fla., from 2.5 to 5 km above sea level, where they were −14 to −18 percent. By comparison of the data for El Paso, Tex., with those for surrounding stations, it may be inferred that similar departures occurred at that place, at least in the lower few kilometer above the surface. Elsewhere the negative departures were generally confined to the limits of −2 to −6 percent, but with values from −7 to −9 percent over Maxwell Field (Montgomery), Ala., through the stratum 1.5 to 3 km. The most pronounced positive departures from normal occurred over the vicinity of Spokane, Wash., from 3 to 5 km above sea level, with values from +9 to +14 percent. Departures from +9 to +12 percent occurred over Omaha, Nebr., up to 1.5 km above sea level, while similar departures occurred over Lakehurst, N. J., from 4 to 5 km. Elsewhere, the departures were largely within the limits +2 to +7 percent.

Table 3 shows the monthly mean free-air barometric pressures and equivalent potential temperatures. The lowest mean barometric pressures in the free-air up to 5 km prevailed over the north-central part of the country with minima in the vicinity of Sault Ste. Marie, Mich., and Fargo, N. Dak., at moderate and high elevations, and at Omaha, Nebr., up to about 1.5 km above sea level. A trough of low mean pressure thus apparently occurred over the northern and central portions of the Western Plains States with greatest intensity in the lower strata while similar troughs of appreciably less intensity occurred over the Ohio River Basin just west of the Appalachians and over the extreme northeastern part of the country. The

highest mean barometric pressures in the free air occurred over the coastal strip adjacent to the Gulf of Mexico, most pronounced, however, in the lower levels over Miami, Fla., and Pensacola, Fla., and in the upper levels over Miami and San Antonio, Tex. There was evidence of a weak wedge of mean high pressure extending from south to north over the Western Plateau region at moderate and higher elevations.

The mean isobaric charts for April indicate cyclonic curvature over the north-central portion of the country, and anticyclonic curvature over the southeastern and southwestern portions, especially marked in the lower few kilometers above the ground. The prevailing conditions were thus conducive to the transport of warm, moist air in the lower levels from the Gulf of Mexico over the extreme eastern portion of the country, and colder, less moist air from the northwest over the north-central portion.

On the assumption that the differences between the mean monthly barometric pressures given for the various pairs of stations are representative of the mean pressure gradients between the same pairs of stations during the month, the mean pressures afford evidence that the mean gradients from Pensacola, Fla., to Fargo, N. Dak., have increased 75 percent at 1 km and 10 percent at 2.5 km with respect to the gradients for the preceding month, while from Pensacola to Sault Ste. Marie, Mich., they have decreased about 30 percent at all levels up to 5 km. This is explained by the deepening of the statistical low pressure system over Fargo, the filling of the system over Sault Ste. Marie, and the constancy of the high pressure over Pensacola. At 0.5 and 1 km, the mean gradients between Oakland, Calif., and Fargo, reversed direction from March to April, with higher pressure resulting over the former place, and the Oakland to Fargo gradients at 1.5 to 2.5 km increased 300 to 100 percent, respectively, but at elevations 3 to 5 km only 38 to 0 percent. However, the mean gradients between San Antonio, Tex., and Oakland decreased 80 to 30 percent at the elevations from 1 to 3 km, respectively.

Table 4 shows the free-air resultant winds based on pilot-balloon observations made near 5 a. m. (75th meridian time) during April. Generally speaking, the resultant winds were largely normal in direction and mostly above normal in velocity by slight amounts (3 m. p. s.), with minor exceptions. Over Pensacola at 0.5 and 1 km, the resultant winds were oriented from 135° to 50° clockwise from normal, and velocity departures of +1.8 and +3.2 m. p. s., i. e. with stronger westerly components than usual. Over Sault Ste. Marie, clockwise orientations with respect to normal also prevailed, with departures ranging from 50° at the surface, 40° at 0.5 km, 150° at 1 and 1.5 km, and 15° to 50° from 2 to 3 km, hence up to 1.5 km, easterly components predominated by replacing the usual northerly components. The resultant wind velocities were mostly 3 to 4 m. p. s. in excess of normal over Seattle, Wash., up to 2.5 km. Similar or slightly larger departures occurred over Medford, Oreg., and Oakland, Calif., at 4 km. Departures of opposite sign were most common over the northeastern portion of the country, with departures from −2 to −4 m. p. s. over Boston, Mass., up to 3 km, and smaller departures at neighboring places.

Table 5 shows maximum free-air wind velocities and directions for various sections of the United States during April as determined by pilot balloon observations. The extreme was 51.3 m. p. s. from the southwest at 2,290 meters above sea level over Winslow, Ariz.

The mean monthly equivalent potential temperatures and specific humidities are shown in tables 2 and 3, respectively. Charts of the latter element indicate notable deficiencies of moisture content over El Paso, Tex., with respect to surrounding stations, and slight excesses over Salt Lake City, Utah.

While the temperature conditions during April did not depart greatly from normal as already pointed out, marked contrast in the relative amount of precipitation compared to normal occurred in different sections of the country. A considerable number of anticyclones associated with shallow P_c and N_{Pc} air masses moved down over the northwestern and north-central parts of the country from Canada during the month. These advanced southward, southeastward, eastward, and northeastward in a trajectory which frequently included the Great Plains and the Mississippi Valley. Thus shallow N_{Pc} overlain by N_{P} and P_{P} air masses not infrequently moved down over the Gulf States and the Gulf of Mexico. The relatively warm, moist conditions in these regions quickly transformed them into shallow T_A air masses.

At the same time, a number of anticyclones associated with P_P and N_{PP} air masses from the Pacific crossed the western coast of the country, as did a smaller number of cyclones, mostly from the region of the Aleutian Islands, hence in more northerly latitudes as a rule. These disturbances were effective in bringing about the transport of N_{PP} and T_P air into the warm sectors of the cyclones during their passage over the northwest coastal region, thus contributing to the copious precipitation 150 to 300 percent of normal which occurred in that area.

The P_P and N_{PP} air masses on crossing the west coast were frequently characterized by marked subsidence in the upper layers especially after passing the central portion of the Western Plateau. This produced exceedingly low relative humidities on many occasions over the entire Southwest, and some of the central part of the country where precipitation throughout a considerable area during April was only from 0 to 50 percent of normal.

An appreciable number of small cyclones, in some cases along old occluded fronts, developed along the fronts of the P_P and N_{PP} air masses when advancing across the relatively warm sections of the extreme Southwest. Owing to the great dryness in this region, precipitation was scanty from this source, but when the air masses in question reached the P_c and N_{Pc} air masses along the eastern flanks of the Plateau, more well-defined warm sectors formed in the eastward progressing cyclones and the precipitation was not so meager. Further movement of these disturbances toward the Gulf States caused the N_{PP} air in the warm sectors to be replaced by the much warmer, and more moist T_A air masses from that neighborhood with the consequences that the cyclones became more energetic and precipitation more plentiful. Frequently aided by the circulation from the Gulf of Mexico during the occurrence of some well-marked transient anticyclone off the South Atlantic seaboard, the supply of moisture transported across the Gulf States northeastward up the Mississippi Valley east of the river was quite considerable and with the rapid development of the cyclones, precipitation over much of the area just specified generally reached amounts which totaled from 150 to 200 percent of normal during the month, with minor exceptions.

TABLE 1.—*Mean free-air temperatures (t), °C. obtained by airplanes during April 1937. (Dep. represents departure from "normal" temperature)*

Station	Altitude (meters) m. s. l																			
	Surface			500		1,000		1,500		2,000		2,500		3,000		4,000		5,000		
	Number of obs.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.
Barksdale Field [1] (Shreveport), La. (52 m)	29	14.3	----	14.2	----	13.0	----	11.6	----	9.0	----	6.7	----	4.0	----	−2.5	----	----	----	----	----
Billings, Mont.[2] (1,089 m)	30	4.3	+2.0	----	----	----	----	5.8	+1.8	3.1	+1.4	−0.5	+1.0	−4.3	+0.7	−11.5	+0.3	−18.1	+0.2	----	----
Boston, Mass.[1] (5 m)	25	5.3	−1.2	4.3	+0.1	2.1	−0.1	0.0	−0.4	−1.3	+0.3	−3.5	+0.3	−5.7	+0.3	−11.0	−0.1	----	----	----	----
Cheyenne, Wyo.[2] (1,873 m)	30	0.7	−0.1	----	----	----	----	----	----	1.7	0.0	−0.5	−0.9	−3.5	−0.8	−10.8	−1.2	−18.3	−1.3	----	----
Coco Solo, Canal Zone [3] (15 m)	30	25.8	----	23.6	----	21.2	----	19.0	----	17.0	----	15.3	----	13.0	----	7.4	----	2.0	----	----	----
El Paso, Tex.[2] (1,194 m)	30	12.8	----	----	----	----	----	15.8	----	12.9	----	9.3	----	5.4	----	−1.3	----	−8.0	----	----	----
Fargo, N. Dak.[2] (274 m)	28	3.0	+2.3	3.7	+2.1	1.9	+1.7	−0.7	+1.2	−3.0	+1.0	−5.6	+0.7	−8.2	+0.6	−12.8	+0.9	−19.0	+0.7	----	----
Kelly Field (San Antonio), Tex.[1] (206 m)	26	14.0	−1.2	16.3	−0.2	15.8	0.0	14.6	−0.1	13.2	+0.2	10.7	+0.2	8.0	+0.7	1.0	+0.7	−6.4	+0.3	----	----
Lakehurst, N. J.[2] (39 m)	25	5.6	0.0	5.8	+0.4	3.6	+0.3	1.9	+0.5	−0.7	0.0	−2.8	+0.1	−4.6	+0.4	−10.1	−0.1	−15.8	−0.4	----	----
Maxwell Field (Montgomery), Ala.[1] (52 m)	28	14.8	−0.3	15.0	−0.8	12.1	−1.2	9.9	−0.8	7.8	−0.5	5.5	−0.3	3.4	+0.2	−2.2	+0.4	−9.1	0.0	----	----
Miami, Fla.[2] (4 m)	30	18.8	----	19.5	----	16.2	----	13.5	----	11.3	----	9.7	----	7.3	----	1.8	----	−3.6	----	----	----
Mitchel Field (Hempstead, L. I.), N. Y.[1] (29 m)	26	4.9	−0.5	7.0	+0.9	5.2	+1.1	3.2	+1.3	1.1	+1.2	−1.0	+1.4	−3.3	+1.1	−9.3	+0.6	----	----	----	----
Murfreesboro, Tenn.[2] (174 m)	30	10.5	+0.4	12.0	+0.4	9.8	0.0	7.2	−0.4	4.4	−0.8	2.1	−0.8	−0.7	−1.0	−6.4	−1.0	−12.8	−1.0	----	----
Norfolk, Va.[2] (10 m)	19	9.0	−2.2	8.8	−2.1	6.9	−1.9	4.3	−2.1	1.9	−2.1	−0.2	−1.8	−2.6	−1.5	−8.4	+0.3	−14.9	−0.4	----	----
Oakland, Calif.[2] (2 m)	30	10.1	----	9.8	----	9.1	----	7.0	----	4.5	----	2.0	----	−1.0	----	−7.1	----	−13.3	----	----	----
Oklahoma City, Okla.[2] (391 m)	29	11.4	0.0	12.9	+0.3	13.9	+1.4	12.4	+1.0	10.5	+1.0	7.4	+1.0	4.1	+1.2	−3.4	+1.1	−11.6	+0.9	----	----
Omaha, Nebr.[2] (300 m)	30	6.9	+0.2	7.2	−0.1	5.9	−0.9	4.4	−0.6	2.3	−0.5	−0.2	−0.6	−2.8	−0.4	−8.8	−0.1	−15.6	+0.1	----	----
Pensacola, Fla.[2] (13 m)	27	15.5	−2.1	15.9	−0.5	13.4	−1.1	11.3	−1.2	9.3	−1.0	7.8	+0.1	5.1	+0.1	−0.4	+0.9	−6.5	+1.3	----	----
St. Thomas, Virgin Islands [3] (8 m)	26	23.8	----	21.3	----	18.5	----	15.1	----	12.5	----	11.1	----	9.3	----	5.2	----	−0.2	----	----	----
Salt Lake City, Utah [2] (1,288 m)	30	4.5	----	----	----	----	----	6.9	----	4.1	----	0.7	----	−2.9	----	−8.8	----	−14.3	----	----	----
San Diego, Calif.[2] (10 m)	28	12.2	−3.0	12.6	−0.6	12.4	0.0	11.0	+0.1	8.8	−0.2	6.4	+0.2	4.3	+0.8	−0.4	+1.4	−7.6	+1.1	----	----
Sault Ste. Marie, Mich.[2] (221 m)	28	1.4	----	1.8	----	0.0	----	−1.6	----	−3.1	----	−4.9	----	−7.3	----	−13.0	----	−19.1	----	----	----
Scott Field (Belleville), Ill.[1] (135 m)	22	7.4	+0.7	9.7	+0.2	8.5	+0.5	6.4	+0.5	3.5	−0.2	0.4	−0.7	−2.1	−0.8	−8.0	−1.0	−15.1	−1.5	----	----
Seattle, Wash.[2] (10 m)	5	11.5	----	7.3	----	3.3	----	0.2	----	−2.6	----	−4.7	----	−6.9	----	−12.8	----	−18.2	----	----	----
Selfridge Field (Mount Clemens), Mich.[1] (177 m)	28	4.1	----	5.4	----	4.6	----	2.4	----	0.0	----	−2.0	----	−4.4	----	−9.6	----	−15.8	----	----	----
Spokane, Wash.[2] (506 m)	30	5.0	−0.5	----	----	6.4	−0.1	3.9	−0.6	0.2	−1.0	−3.5	−1.3	−7.0	−1.5	−13.0	−1.5	−19.2	−1.0	----	----
Washington, D. C.[1] (13 m)	22	7.7	−2.1	8.4	0.0	5.5	−0.6	3.3	−0.5	1.3	−0.4	−0.2	−0.1	−2.7	−0.5	−8.4	−0.9	−14.6	−1.4	----	----
Wright Field (Dayton), Ohio [1] (244 m)	28	6.4	+0.6	8.2	+0.9	6.7	+0.8	4.7	+0.8	2.4	+0.6	−0.5	+0.1	−3.0	−0.1	−8.5	−0.3	−15.7	−1.1	----	----

[1] Army.
[2] Weather Bureau.
[3] Navy.
Observations taken about 4 a. m., 75th meridian time, except by Navy stations along the Pacific coast and Hawaii where they are taken at dawn.

NOTE.—The departures are based on normals covering the following total number of observations made during the same month in previous years, including the current month (years of record are given in parentheses following the number of observations): Billings, 89 (3); Boston, 96 (4); Cheyenne, 88 (3); Fargo, 88 (3); Kelly Field, 84 (3); Lakehurst, 72 (3); Maxwell Field, 75 (3); Mitchel Field, 74 (3); Murfreesboro, 90 (3); Norfolk, 149 (8); Oklahoma City, 88 (3); Omaha, 179 (6); Pensacola, 205 (9); San Diego, 190 (8); Scott Field, 69 (3); Spokane, 90 (3); Washington, 229 (11); Wright Field, 80 (3)

TABLE 2.—*Mean free-air relative humidities (R. H.), in percent, and specific humidities (q), in grams/kilogram, obtained by airplanes during April 1937 (Dep. represents departure from "normal" relative humidity)*

Station	Altitude (meters) m. s. l																				
	Surface				500			1,000			1,500			2,000			2,500			3,000			4,000			5,000		
	Number of observations	q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.	
			Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.
Barksdale Field, La.	29	7.9	78	----	7.2	68	----	6.1	59	----	5.1	51	----	3.7	41	----	3.0	37	----	2.3	33	----	1.6	31	----	----	----	----
Billings, Mont.	30	3.6	62	−6	----	----	----	----	----	----	3.5	51	−6	3.1	51	−5	2.8	57	−3	2.4	61	−2	1.7	66	+2	0.9	55	−2
Boston, Mass.	25	3.9	71	+1	3.6	67	0	3.3	66	+2	3.0	67	+5	2.8	63	+1	2.2	58	−3	1.9	54	−4	1.5	55	+1	----	----	----
Cheyenne, Wyo.	30	3.6	72	+1	----	----	----	----	----	----	----	----	----	3.6	66	0	3.0	60	+1	2.3	58	0	1.6	58	+1	1.0	50	+1
Coco Solo, Canal Zone	30	17.7	85	----	17.1	89	----	15.5	88	----	13.6	84	----	11.2	74	----	8.8	61	----	7.1	54	----	4.7	46	----	3.5	44	----
El Paso, Tex.	30	2.6	25	----	----	----	----	----	----	----	2.7	20	----	2.2	19	----	1.8	18	----	1.5	19	----	1.1	20	----	0.8	20	----
Fargo, N. Dak.	28	4.1	84	+1	4.0	76	+3	3.6	74	+6	3.1	71	+6	2.7	69	+5	2.3	67	+6	1.9	63	+4	1.4	60	+4	1.0	62	+8
Kelly Field, Tex.	26	8.0	79	−3	8.7	71	−4	7.0	56	−6	5.7	47	−4	4.6	39	−2	3.7	34	−3	3.1	32	−3	2.2	33	−2	1.7	37	+2
Lakehurst, N. J.	25	4.3	76	−2	4.1	67	0	3.7	66	+1	3.4	63	−2	3.1	68	+1	2.9	68	+3	2.5	62	+3	1.7	60	+9	1.2	61	+12
Maxwell Field, Ala.	28	7.9	75	−2	6.3	56	−4	5.3	55	−3	4.2	47	−7	3.5	41	−9	3.0	39	−7	2.4	35	−7	1.6	32	−2	1.0	30	−1
Miami, Fla.	30	11.9	89	----	11.3	76	----	9.6	75	----	7.8	69	----	6.5	62	----	4.9	49	----	3.8	42	----	2.7	39	----	2.0	37	----
Mitchel Field, N. Y.	26	4.2	79	+2	4.8	73	+4	4.4	71	+5	3.9	67	+2	3.7	69	+3	3.3	70	+6	2.9	68	+4	1.8	62	+4	----	----	----
Murfreesboro, Tenn.	30	6.3	79	−3	5.8	63	−8	5.4	65	−5	4.7	63	−4	4.0	61	−5	3.5	59	−3	2.8	55	−3	1.6	43	−6	1.0	42	−4
Norfolk, Va.	19	5.0	71	+1	4.4	57	−1	3.9	55	−1	3.6	59	+4	3.3	58	+4	2.7	53	+1	2.1	49	−2	1.3	43	−6	0.8	41	−3
Oakland, Calif.	30	6.3	83	----	5.5	70	----	4.3	54	----	3.5	48	----	2.8	40	----	1.9	33	----	1.7	33	----	1.2	33	----	0.9	34	----
Oklahoma City, Okla.	29	6.8	77	+9	6.8	69	+4	6.0	55	−1	5.0	47	0	4.1	41	−1	3.6	41	0	2.9	39	−3	1.8	38	−4	1.0	41	+1
Omaha, Nebr.	30	5.2	81	+10	5.2	78	+10	4.9	75	+12	4.3	68	+9	3.6	63	+7	3.0	59	+5	2.5	57	+4	1.9	56	+3	1.0	52	0
Pensacola, Fla.	27	9.4	86	+6	8.4	71	+1	6.8	63	0	5.3	53	−3	4.2	45	−5	2.8	32	−14	2.1	26	−18	1.4	24	−18	0.8	21	−16
St. Thomas, Virgin Islands	26	15.7	85	----	14.7	88	----	12.8	87	----	10.8	85	----	9.0	79	----	6.8	61	----	4.9	47	----	2.4	27	----	1.1	19	----
Salt Lake City, Utah	30	4.0	67	----	----	----	----	----	----	----	4.4	60	----	3.8	59	----	3.3	61	----	2.9	66	----	2.1	67	----	1.5	63	----
San Diego, Calif.	28	7.3	83	+9	7.1	75	0	6.0	60	−1	4.7	48	−1	3.9	42	+3	3.1	39	+5	2.6	36	+7	1.8	31	+8	1.1	30	+8
Sault Ste. Marie, Mich.	28	3.6	83	----	3.6	77	----	3.2	76	----	3.0	74	----	2.6	66	----	2.2	61	----	2.0	59	----	1.1	50	----	0.7	47	----
Scott Field, Ill.	22	5.0	78	−1	4.7	58	+1	4.0	51	−2	3.4	47	−3	2.7	46	−3	2.4	46	−2	2.0	42	−5	1.3	39	−5	0.9	42	−1
Seattle, Wash.	5	5.0	61	----	4.1	63	----	3.4	64	----	2.8	62	----	2.3	60	----	1.9	56	----	1.7	54	----	1.2	55	----	1.0	58	----
Selfridge Field, Mich.	28	4.2	82	----	4.3	72	----	3.9	66	----	3.4	63	----	3.0	60	----	2.6	58	----	2.2	55	----	1.5	49	----	1.0	48	----
Spokane, Wash.	30	4.6	79	+6	----	----	----	4.4	67	+3	3.8	65	+4	3.4	70	+6	2.9	74	+7	2.6	76	+9	1.9	77	+14	1.0	74	+12
Washington, D. C.	22	4.8	73	+7	4.4	61	+1	4.0	63	+4	3.5	59	+2	3.2	61	+5	2.7	53	0	2.2	48	−2	1.4	41	−6	0.9	34	−10
Wright Field, Ohio	28	5.0	81	+1	4.8	66	−5	4.5	65	−3	4.0	63	−3	3.4	59	−5	2.9	57	−5	2.4	54	−5	1.4	43	−9	0.9	44	−5

TABLE 3.—*Mean free-air barometric pressures (P), in mb, and equivalent potential temperatures (θ_w), in °A. obtained by airplanes during April 1937*

Stations	Altitude (meters) m. s. l.																			
	Surface			500		1,000		1,500		2,000		2,500		3,000		4,000		5,000		
	Number of observations	P	θ_w	P	θ_w	P	θ_w	P	θ_w	P	θ_w	P	θ_w	P	θ_w	P	θ_w	P	θ_w	
Barksdale Field, La.	29	1,008	309	955	311	900	312	848	313	799	312	751	313	707	314	624	315			
Billings, Mont.	30	888	298					845	303	795	304	746	305	701	305	616	306	541	307	
Boston, Mass.	25	1,017	288	957	291	900	293	846	295	794	299	745	300	699	302	613	307			
Cheyenne, Wyo.	30	808	302							795	304	746	306	701	306	616	306	541	307	
Coco Solo, Canal Zone	30	1,009	348	952	350	899	349	849	348	800	343	754	340	711	338	630	336	559	337	
El Paso, Tex.	30	879	305					847	312	798	312	752	312	708	312	626	314	552	317	
Fargo, N. Dak.	28	980	289	954	292	898	294	842	295	791	297	742	299	696	300	610	304	535	308	
Kelly Field, Tex.	26	991	310	958	318	904	318	852	318	803	319	756	319	712	320	631	320	557	321	
Lakehurst, N. J.	25	1,012	290	956	294	899	296	846	299	795	300	746	303	701	305	616	308	541	311	
Maxwell Field, Ala.	28	1,009	309	958	309	902	309	850	309	800	310	753	312	708	313	625	315	551	317	
Miami, Fla.	30	1,016	323	959	328	905	325	853	323	804	323	757	321	712	322	630	323	556	326	
Mitchel Field, N. Y.	26	1,014	289	957	297	900	300	846	301	796	304	747	306	702	308	627	307			
Murfreesboro, Tenn.	30	994	302	955	305	900	307	847	308	798	308	750	310	704	310	621	311	546	313	
Norfolk, Va.	19	1,016	295	958	298	902	300	849	301	798	304	750	304	704	305	620	308	546	310	
Oakland, Calif.	30	1,019	299	960	302	903	303	850	304	800	305	752	305	707	306	622	309	547	312	
Oklahoma City, Okla.	29	965	306	953	309	898	314	846	315	797	316	750	316	706	315	623	315	550	314	
Omaha, Nebr.	30	976	296	952	299	896	302	842	304	792	305	744	306	700	307	615	310	541	311	
Pensacola, Fla.	27	1,016	313	960	316	905	314	852	313	802	314	754	313	710	313	627	317	553	319	
St. Thomas, Virgin Islands	26	1,016	339	961	339	907	337	855	333	806	330	758	328	714	326	632	326	560	326	
Salt Lake City, Utah	30	870	300					849	306	799	307	750	307	705	308	621	310	546	313	
San Diego, Calif.	28	1,014	304	956	309	901	311	849	312	799	313	752	313	707	315	625	318	551	319	
Sault Ste. Marie, Mich.	28	988	285	955	289	897	291	842	294	790	297	742	299	696	301	611	303	536	306	
Scott Field, Ill.	22	999	294	957	300	901	302	848	303	798	304	749	305	704	306	620	308	545	310	
Seattle, Wash.	5	1,019	297	960	295	902	295	849	295	798	296	749	297	702	300	617	303	540	307	
Selfridge Field, Mich.	28	993	289	954	294	898	297	845	299	795	300	746	303	701	305	617	308	542	310	
Spokane, Wash.	30	944	296			899	301	845	302	795	302	746	302	704	302	615	305	539	307	
Washington, D. C.	22	1,017	293	958	297	901	299	848	300	796	303	749	305	704	306	619	308	544	312	
Wright Field, Ohio	28	985	295	954	298	898	301	845	303	795	304	746	306	702	307	618	308	543	310	

TABLE 4.—*Free-air resultant winds (meters per second) based on pilot-balloon observations made near 5 a. m. (E. S. T.) during April 1937*

[Wind from N=360°, E=90°, etc.]

Altitude (meters) m. s. l.	Albuquerque, N. Mex. (1,554 m)		Atlanta, Ga. (309 m)		Billings, Mont. (1,088 m)		Boston, Mass. (15 m)		Cheyenne, Wyo. (1,873 m)		Chicago, Ill. (192 m)		Cincinnati, Ohio (153 m)		Detroit, Mich. (204 m)		Fargo, N. Dak. (274 m)		Houston, Tex. (21 m)		Key West, Fla. (11 m)		Medford, Oreg. (410 m)		Murfreesboro, Tenn. (180 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°		°	
Surface	308	2.3	279	1.4	274	2.3	343	1.4	277	2.9	130	0.5	270	0.3	186	0.3	26	2.0	156	0.4	101	2.1	320	0.8	194	1.8
500			270	4.4			339	3.5			202	2.9	211	3.5	196	0.8	68	0.9	189	4.2	120	4.2	312	1.1	204	4.6
1,000			263	5.5			358	4.3			234	5.2	239	7.1	261	2.4	247	0.9	200	5.0	150	3.0	247	1.2	235	5.1
1,500			265	7.1	276	4.2	316	3.9			242	5.6	257	8.5	268	6.0	283	3.7	258	3.8	186	3.1	216	2.7	252	7.7
2,000	284	3.9	267	8.3	282	4.2	330	5.8	274	5.0	245	5.4	260	6.8	296	7.1	332	2.8	283	6.0	229	3.3	224	5.3	272	8.9
2,500	290	6.0	272	9.2	287	4.9	323	6.1	278	8.3	302	5.8	268	6.1	297	8.1	337	6.0	298	9.4	272	2.3	269	4.7	286	9.6
3,000	280	7.8	278	9.5	289	6.2	344	7.0	289	9.8			288	7.5	303	8.8	309	9.1	276	6.8	297	3.3	259	4.7	295	9.3
4,000	269	10.1			284	6.8			289	11.4									292	4.6			297	10.3		
5,000	282	9.8																								

Altitude (meters) m. s. l.	Newark, N. J. (14 m)		Oakland, Calif. (8 m)		Oklahoma City, Okla. (402 m)		Omaha, Nebr. (306 m)		Pearl Harbor, Territory of Hawaii[1] (68m)		Pensacola, Fla.[1] (24 m)		St. Louis, Mo. (170 m)		Salt Lake City, Utah (1,294 m)		San Diego, Calif. (15 m)		Sault Ste. Marie, Mich. (198 m)		Seattle, Wash. (14 m)		Spokane, Wash. (603 m)		Washington, D. C. (10 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°		°	
Surface	342	1.2	295	1.0	175	1.8	81	0.3	64	3.4	307	1.0	202	1.4	148	1.8	107	0.8	90	1.8	175	2.6	177	1.6	305	0.6
500	344	3.5	307	3.5	166	3.6	205	1.5	72	7.0	250	3.1	211	4.1			348	0.6	98	4.0	197	5.7			295	3.5
1,000	319	2.1	324	4.2	227	8.1	258	5.2	81	6.2	284	3.7	241	6.5			345	3.2	121	3.7	192	6.6	208	4.1	292	7.3
1,500	294	4.0	312	4.5	256	7.8	259	7.8	89	4.9	287	5.0	269	7.4	144	1.6	344	2.3	100	0.8	202	5.9	229	5.2	295	9.7
2,000	305	6.1	309	4.8	263	8.3	274	9.1	100	3.9	298	5.1	279	6.2	221	0.6	11	1.6	332	1.4	215	3.9	241	5.7	299	10.6
2,500	312	10.5	306	5.1	277	9.1	302	8.6	101	2.6	326	4.5	286	6.8	237	3.0	353	2.0	346	2.2	234	6.6	226	5.3	287	10.2
3,000	307	10.3	306	5.3	281	7.2	299	9.9	101	2.2	308	5.3	281	8.2	259	4.6	314	4.2	6	4.7			233	3.8	289	13.3
4,000			327	9.6					336	0.8	277	5.0			259	7.4	290	6.0								
5,000															294	10.6										

[1] Navy stations.

TABLE 5.—*Maximum free-air wind velocities (M. P. S.), for different sections of the United States based on pilot-balloon observations during April 1937*

Section	Surface to 2,500 meters (m. s. l.)					Between 2,500 and 5,000 meters (m. s. l.)					Above 5,000 meters (m. s. l.)				
	Maximum velocity	Direction	Altitude (m) M. s. L.	Date	Station	Maximum velocity	Direction	Altitude (m) M. s. L.	Date	Station	Maximum velocity	Direction	Altitude (m) M. s. L.	Date	Station
Northeast [1]	30.5	W	1,190	18	Pittsburgh	36.4	WNW	4,450	20	Buffalo	42.4	N	8,460	12	Albany.
East-Central [2]	33.7	WSW	1,500	14	Cincinnati	41.2	N	5,000	16	Greensboro	42.5	N	5,220	16	Greensboro.
Southeast [3]	31.5	SW	2,084	5	Jacksonville	38.0	WSW	4,530	25	Atlanta	36.5	WNW	7,664	12	Jacksonville.
North-Central [4]	34.7	W	1,370	13	Detroit	32.0	WNW	5,000	19	Detroit	35.4	WNW	5,330	19	Detroit.
Central [5]	41.0	SW	1,230	17	Wichita	30.5	WNW	2,622	13	Chicago	30.0	NW	5,740	1	Wichita.
South-Central [6]	37.2	SSW	1,527	6	Abilene	36.4	W	5,000	24	Dallas	37.2	W	5,100	24	Dallas.
Northwest [7]	27.4	SSW	1,374	4	Portland	34.6	SSW	5,000	25	Medford	35.0	SSW	5,180	25	Medford.
West-Central [8]	36.2	W	2,470	6	Modena	51.0	WSW	4,856	15	Reno	51.2	WNW	6,970	6	Modena.
Southwest [9]	51.3	SW	2,290	22	Winslow	43.2	NW	4,705	3	Fresno	46.8	W	8,130	25	El Paso.

[1] Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, and northern Ohio.
[2] Delaware, Maryland, Virginia, West Virginia, southern Ohio, Kentucky, eastern Tennessee, and North Carolina.
[3] South Carolina, Georgia, Florida, and Alabama.
[4] Michigan, Wisconsin, Minnesota, North Dakota, and South Dakota.
[5] Indiana, Illinois, Iowa, Nebraska, Kansas, and Missouri.
[6] Mississippi, Arkansas, Louisiana, Oklahoma, Texas (except El Paso), and western Tennessee.
[7] Montana, Idaho, Washington, and Oregon.
[8] Wyoming, Colorado, Utah, northern Nevada, and northern California.
[9] Southern California, southern Nevada, Arizona, New Mexico, and extreme west Texas.

LATE REPORTS

TABLE 1.—*Mean free-air temperatures (t), °C obtained by airplanes during March 1937. (Dep. represents departure from "normal" temperature.)*

Station	Altitude (meters) m. s. l.																			
	Surface			500		1,000		1,500		2,000		2,500		3,000		4,000		5,000		
	Number of observations	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.	t	Dep.
Pearl Harbor, T. H.[1] (6 m)	31	19.9	−2.1	18.1	−1.6	15.1	−1.1	12.4	−0.8	10.3	−0.7	9.4	−0.2	7.4	−0.1	2.3	0.0	−3.7	−1.4		

[1] Navy; observations taken at dawn:

NOTE.—The departures are based on normals covering the following total number of observations made during the same month in previous years, including the current month years of record are given in parenthesis following the number of observations): Pearl Harbor, 143 (6).

TABLE 2.—*Mean free-air relative humidities (R. H.), in percent, and specific humidities (q), in grams/kilogram, obtained by airplanes during March 1937 (Dep. represents departure from "normal" relative humidity.)*

Station	Altitude (meters) m. s. l.																							
	Surface				500			1,000			1,500			2,000			2,500			3,000			4,000			5,000		
	Number of observations	q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.		q	R. H.	
			Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.		Mean	Dep.
Pearl Harbor, T. H.	31	11.8	83	+9	11.1	82	+6	10.3	87	+8	8.7	83	+7	7.1	73	+5	4.9	80	−2	3.7	40	−1	2.2	31	+2	1.5	28	+1

TABLE 3.—*Mean free-air barometric pressures (P), in mb, and equivalent potential temperatures (Θ_E), in °A obtained by airplanes during March 1937*

Station	Altitude (meters) m. s. l.																			
	Surface			500		1,000		1,500		2,000		2,500		3,000		4,000		5,000		
	Number of observations	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E	P	Θ_E
Pearl Harbor, T. H.	31	1,015	324	959	326	904	326	852	324	803	323	755	32.1	711	321	628	322	554	324		

RIVERS AND FLOODS

[River and Flood Division, MERRILL BERNARD in charge]

By BENNETT SWENSON

Report on flood losses suffered during February and March in some of the tributaries of the upper Mississippi River in Iowa and Illinois were received too late for inclusion in the March MONTHLY WEATHER REVIEW and are presented herewith. The damages were caused mainly by the forming and breaking of ice gorges, and summarized according to rivers, are as follows: Des Moines River between Swan and Eldon, Iowa, about $45,000; Rock River in Illinois, $185,000; Maquoketa and Wapsipinicon Rivers in Iowa, $154,000; Galena River in Illinois, $150,000 and 3 lives lost; and in the Iowa and Cedar Rivers in Iowa, $13,300.

The precipitation over the United States during April varied greatly in different areas. The monthly totals were above normal rather generally in the upper Mississippi Valley, the Lake region, the Atlantic and the central and eastern Gulf States, and in the far Northwest. The relatively heaviest amounts fell in the Atlantic States from North Carolina northward to Pennsylvania, and in portions of the far Northwest. On the other hand, a large southwestern area had very little rain and in much of the western plains the amounts were scanty.

St. Lawrence drainage.—A heavy wet snow on the 15th in central Michigan followed by moderately heavy rains during the next 3 days caused rises in the Red Cedar and Grand Rivers. The combined rain and melted snow amounted to about 3 inches of water in this section. The Red Cedar at East Lansing, Mich., reached a crest of 0.9 foot above flood stage on the 18th and lowlands between Lansing and East Lansing were flooded to some extent.

The Grand River did not reach flood stage at Lansing and there was only slight flooding of the lowlands from this river. No damage of consequence was reported from these overflows.

Atlantic slope drainage.—Slight flooding occurred in the Susquehanna River and its tributaries in New York the first week of April due to the melting of the winter snow and ice covering as a result of high temperatures the first few days of the month. The overflow was not severe and no damage of consequence occurred.

Another flood occurred in the lower Susquehanna Basin from the 26th to the 28th as a result of heavy rainfall which occurred on the 26th and 27th and which will be discussed below in connection with the floods to the southward. In the Frankstown Branch flood stage was exceeded by 0.8 foot at Huntingdon, Pa., and in the Juniata River at Newport, Pa., by 2.4 feet. The total damage reported amounted to approximately $250,000.

A disturbance that was first noted over the Southeastern States on the 24th moved northeastward with increasing intensity to North Carolina. Further movement was blocked by an abnormally persistent and stable mass of air which had previously moved southward over the North Atlantic States from the Hudson Bay region. The storm remained practically stationary for 48 hours, with its center near the Virginia-North Carolina border, and continuous rain occurred over the region immediately to the north until finally the disturbance began to lose energy.

The rainfall was excessive in some sections with the area of heaviest precipitation extending approximately from central North Carolina northward into portions of Pennsylvania. The rain began over most of this area on the night of the 24th and did not cease until the evening of the 27th in the northern portions. The period of heaviest rainfall occurred on the 25th and 26th. The greatest 24-hour precipitation recorded was 5.84 inches at Clear Spring, Md., for the 24-hour period ending 6 p.m. of the 26th and 5.12 inches at Riverton, Va., for the 24-hour period ending 8 a.m. of the same date. During the period April 24–27, inclusive, amounts in excess of 7 inches occurred over portions of the James, Rappahannock, and Potomac River Basins, the greatest amount reported during this period was 11.62 inches at Clear Spring, Md. Daily and total amounts of precipitation for a few representative stations in this area are given in table 1.

TABLE 1.—*Daily and total precipitation in inches and hundredths, Apr. 25–28, inclusive, 1937*

	April—				Total
	25	26	27	28	
James River Basin	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Afton, Va.	3.40	2.50	0.17	------	6.07
Charlottesville, Va.[1]	5.10	1.87	.22	0.01	7.20
Columbia, Va.[2]	2.25	4.16	.16	0.27	6.84
Lexington, Va.[2]	2.40	.23	.02	.11	2.76
Lynchburg, Va.	1.18	1.82	------	.11	3.11
Richmond, Va.	.52	2.18	.03	.26	2.99
Rappahannock River Basin					
Culpeper, Va.[2]	2.75	4.25	.50	.20	7.70
Potomac River Basin					
Bayard, W. Va.[2]	1.03	1.57	.07	------	2.67
Circleville, W. Va.	.18	2.45	.32	.51	3.46
Clear Spring, Md.[2]	2.05	5.84	1.68	2.05	11.62
Cumberland, Md.	.20	3.33	.25	.52	4.30
Dale Enterprise, Va.[2]	1.78	1.87	.27	------	3.92
Emmitsburg, Md.[2]	1.87	3.72	.68	1.23	7.50
Hancock, Md.	.08	4.00	1.32	1.07	6.47
Harpers Ferry, W. Va.	.09	3.65	1.08	1.62	6.44
McNeill, W. Va.[2]	1.62	3.02	.29	.13	5.06
Mount Weather, Va.[2]	.78	2.67	.68	1.37	5.50
Piedmont, W. Va.[2]	1.75	2.23	.18	.16	4.32
Riverton, Va.	.41	5.12	.77	.44	6.74
Shenandoah Camp No. 3, Va.	3.56	3.74	.38	------	7.68
Staunton, Va.	.46	2.83	.12	.33	3.74
Washington, D. C.	.14	2.11	1.54	.56	4.35
Winchester, Va.[2]	1.50	4.43	.12	.64	6.69
Woodstock, Va.	.19	3.15	.45	.45	4.24

[1] Precipitation is for 24-hour period midnight to midnight. 1.00 inch precipitation that occurred during the 24th is not included in the total.
[2] Daily amounts measured in late afternoon.

NOTE.—Except as otherwise indicated daily amounts measured in the morning.

This excessive precipitation caused severe flooding in most of the streams in Virginia and Maryland and in portions of West Virginia and Pennsylvania. Severe flooding occurred in the lower portion of the James River but flood stages were not reached at Lynchburg, Va., and points upstream. The highest stage at Richmond, Va., was only 1.3 feet below the record stage reached in March 1936. The Potomac River Basin suffered its third greatest flood of record, being exceeded only by the record floods of March 1936 and May–June 1889 and was comparable to the flood of May 1924. The Bureau maintains no gages on the Rappahannock River but from reports it appears that the stages on that river were the greatest of record. Fredericksburg, Va., was probably the hardest hit of any of the cities in the flooded area. Table 2 shows stages at a few points in comparison to previous floods.

It is impracticable to give an estimate of flood losses at this time; practically all towns in the flooded areas were inundated to some extent. Roads were damaged, several bridges were washed out, and traffic was delayed considerably, due to the freshet waters. High water along the water-front sections in the tidewater reaches of the rivers

in Virginia, Maryland, and in the Chesapeake Bay region on April 25 and 26, caused by strong easterly winds for an extended period, resulted in considerable damage.

TABLE 2.—*Crest stages for April 1937 compared with a few previous floods*

Station	River	1889	1924	1936	1937
		Feet	*Feet*	*Feet*	*Feet*
Columbia, Va.	James		31.2	35.8	34.4
Richmond, Va.	do	[1] 25.2	20.1	26.5	25.2
Cumberland, Md.	Potomac	29.2	28.4	29.1	24.2
Hancock, Md.	do	39.7	35.0	47.6	35.8
Riverton, Va.	Shenandoah	36.0	34.0	37.5	[2] 27.0
Harpers Ferry, W. Va.	Potomac	36.0	27.6	36.5	29.0
Washington, D. C. (Wisconsin Ave. gage).	do			17.2	14.2

[1] Reading taken on gage ½ mile downstream from present gage.
[2] Approximate. Determined by leveling to high water mark.

Floods, as a result of the passage of the disturbance previously discussed, were less severe south of the Virginia-North Carolina border. Minor floods also occurred in this region the first half of the month. Total losses for the month in this section were as follows: Roanoke River, $35,000; Tar River, $5,000; Neuse River, $6,000; Cape Fear River, $3,000; Peedee River, $16,500; Santee Basin, $6,100; and the Savannah Basin, $2,000.

East Gulf of Mexico Drainage.—The Apalachicola River was at or above flood stage throughout the month but material damage occurred only during the period 8th–19th when a loss of $8,000 was reported.

Heavy to excessive rains in southeastern Alabama on April 4–5 caused moderate floods in the Conecuh, Pea, and Choctawhatchee Rivers. The estimated losses were somewhat in excess of $23,000 for the Conecuh and $12,000 for the Choctawhatchee River while no damage was reported for the Pea River.

Minor flooding occurred in tributaries of the Alabama River and in the Pearl River but no damage of consequence was reported.

Upper Mississippi Basin.—Due to rapid melting of snow and moderately heavy rainfall on the 11th, over the watershed of the Redwood River, a tributary of the Minnesota, a flood occurred in a limited area with the town of Marshall, Minn., as the center. More than 30 homes were isolated when the river crested on the 12th and a property loss of $7,000 was reported.

Stages in the Illinois River began rising near the close of the month, but as the rise continued into May discussion will be deferred until a later issue of the REVIEW.

Missouri Drainage.—Severe flooding attended the spring break-up in the upper Big Sioux River and tributaries as far south as Sioux Falls, S. Dak. From Lincoln County, S. Dak., to the mouth the rise was less pronounced and at Akron, Iowa, where the only official gage on the Big Sioux River is located, the crest reached 12.3 feet, or 0.3 foot above flood stage, on the 14th and again on the 16th. The precipitation over the watershed for the first 3 months of the year was the heaviest since 1929 and additional heavy snow fell again on April 2 and 3. Mild temperatures melted the snow rapidly and by the 10th and 11th the highest stages were reached in the upper tributaries.

The loss to farm crops was not great, due to a crop failure over most of the valley during the 1936 season. The total losses reported amounted to about $90,000 and were confined to the upper reach of the Big Sioux River and tributaries above Sioux Falls, S. Dak.

Ohio Drainage.—Light to moderately heavy rains were frequent over the northern portions of the Ohio River Basin during most of April, maintaining the ground in a well-saturated condition and the streams at or above normal flow. This resulted in flooding or near flooding in most of the northern tributaries of the Ohio River as well as in the upper Ohio River itself.

The flooding was light to moderate in the Scioto River and in the Wabash River system, but no losses of consequence were reported.

More serious flooding occurred in the Allegheny and Monongahela Rivers and tributaries. The flooding in this section was caused by a period of moderately heavy rain from the 21st to 23d and heavy rain on the 25th and 26th following frequent rains during the first 3 weeks of the month. The rainfall averaged 1.85 inches over practically the entire basin above Pittsburgh, Pa., for the afternoon and night of the 25th and at Somerset, Pa., 3.62 inches was recorded for the 24 hours ending the morning of the 26th.

A crest stage of 35.1 feet, or 10.1 feet above flood stage, was reached at Pittsburgh, Pa., on the 27th. This rise resulted in flooding in the Ohio River as far downstream as Point Pleasant, W. Va. Because of timely warnings the damage throughout this area was small, considering the high stages reached at some points. The greatest losses were the suspension of business and the cost of cleaning up after the flood. Statistics on the actual figures are not available at this time. No material losses occurred below Wheeling, W. Va.

Arkansas, Red, and Lower Mississippi River Drainage.—Minor flooding occurred in the Poteau, Sulphur, and St. Francis Rivers during the month, but no damage of consequence resulted.

West Gulf of Mexico Drainage.—Rapid melting of the heavy snow cover on the upper watershed of the Rio Grande resulted in flooding in the vicinity of Espanola and Albuquerque, N. Mex., on April 17 and April 20. The river overflowed the banks at San Marcial, N. Mex., and covered 2,500 acres of rich irrigated farming land with 3 feet of water. The damage resulting from this overflow has been estimated at $50,000.

Columbia River Drainage.—Light rains began over the Willamette Basin the latter part of March and continued almost daily for the first 11 days of April. These rains were followed by heavy rains from the 12th to the 14th over the entire Willamette watershed, accompanied by mild temperatures, resulting in rapid melting of snow in the Cascades. These factors caused the highest April flood of record in the Willamette.

The 4-day total rainfall, April 12–15, inclusive, for stations in the Willamette Basin is given in the following table:

Station	Total rainfall	Station	Total rainfall
	Inches		*Inches*
Albany, Oreg.	4.21	Rujada, Oreg.	4.42
Cascade Summit, Oreg.	4.76	Saginaw, Oreg.	4.04
Detroit, Oreg.	6.23	Salem, Oreg.	4.02
Eugene, Oreg.	3.38	Spring Glade Acres, Oreg.	4.57
Eula, Oreg.	4.43	Summit, Oreg.	4.65
Intake, Oreg.	4.76	Three Links, Oreg.	5.49
Jefferson, Oreg.	4.06	Timber, Oreg.	5.53
Leaburg, Oreg.	4.51	Waterloo, Oreg.	4.26
Mehama, Oreg.	5.43	Willamina, Oreg.	4.62
Portland, Oreg.	3.60		

Average for 19 stations, 4.58 inches.

The total losses, based on a careful study made by the United States Engineer Office, are estimated to be about $600,000. This estimate includes such items as erosion and the delay and rerouting of traffic.

Table of flood stages during April 1937

[All dates in April unless otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ST. LAWRENCE DRAINAGE					
Lake Michigan					
Red Cedar: East Lansing, Mich	*Feet* 8	18	19	*Feet* 8.9	18
ATLANTIC SLOPE DRAINAGE					
Connecticut: South Newbury, Vt	18	29	(1)	20.3	30
Tioughnioga: Whitney Point, N. Y	12	6	8	14.7	7
Chenango: Sherburne, N. Y	8	6	8	9.3	6
Frankstown Branch: Huntingdon, Pa	12	26	28	12.8	27
Juniata: Newport, Pa	22	27	28	24.4	27
Susquehanna:					
Oneonta, N. Y	12	6	7	13.0	6, 7
Bainbridge, N. Y	12	7	7	12.1	7
North Branch of Potomac: Cumberland, Md	17	26	27	24.2	26
Shenandoah: Riverton, Va	22	26	27	² 27.0	27
Potomac:					
Hancock, Md	32	26	27	35.8	27
Harpers Ferry, W. Va	18	26	29	29.0	27
Sycamore Island, Md	10	26	30	23.7	28
Washington, D. C	8	27	29	14.2	28
James:					
Columbia, Va	10	25	(1)	34.4	26
Richmond, Va	8	25	29	25.2	27
Dan: Clarksville, Va	13	27	27	13.6	27
Roanoke:					
Randolph, Va	21	26	28	25.8	27
Weldon, N. C	31	26	30	42.1	28
Williamston, N. C	10	29	(1)	13.0	May 2, 3
Fishing Creek: Enfield, N. C	14	27	29	14.8	28
Tar:					
Rocky Mount, N. C	8	6	6	9.1	6
		26	(1)	9.9	30
Tarboro, N. C	18	28	(1)	22.7	May 1
Greenville, N. C	13	10	13	13.9	12
		28	(1)	16.9	May 3
Little: Kenly, N. C	8	6	10	14.0	6
		26	27	12.2	26
Neuse:					
Neuse, N. C	14	7	9	17.2	9
		26	(1)	17.5	28
Smithfield, N. C	13	7	11	15.6	10
		26	(1)	17.5	28
Goldsboro, N. C	14	8	15	16.8	11
		27	(1)	18.4	May 3
Kinston, N. C	14	11	17	15.3	14
		29	(1)	16.3	May 6
Haw: Moncure, N. C	20	26	26	21.0	26
Cape Fear: Lock No. 2, Elizabethtown, N. C.	20	7	9	21.8	8
		27	(1)	27.0	28
Peedee:					
Cheraw, S. C	30	26	28	34.0	27
Mars Bluff Bridge, S. C	17	11	13	17.5	12
		27	May 5	20.1	May 1
Saluda:					
Pelzer, S. C	6	24	26	7.0	25
Chappells, S. C	15	25	27	17.3	27
Broad: Blairs, S. C	14	25	27	17.3	26
Catawba: Catawba, S. C	11	26	26	11.4	26
Wateree: Camden, S. C	23	26	27	24.7	26
Santee:					
				12.7	2
Rimini, S. C	12	(3)	(1) (4)	15.0	12
				16.4	30
Ferguson, S. C	12	(3)	(1)	13.7	13, 30
Savannah:					
Ellenton, S. C	14	6	20	19.0	12
		25	(1)	21.3	May 3
Clyo, Ga	13	14	22	15.0	17
Ocmulgee:					
Macon, Ga	18	30	(1)	----	----
Abbeville, Ga	11	15	16	11.3	16
Oconee: Milledgeville, Ga	22	30	(1)	----	----
Altamaha: Charlotte, Ga	12	(3)	4	----	----
		8	22	13.6	14, 15
EAST GULF OF MEXICO DRAINAGE					
Apalachicola: Blountstown, Fla	15	(3)	(1)	----	----
Pea: Elba, Ala	30	6	6	30.0	6
Choctawhatchee:					
Newton, Ala	19	6	7	22.6	7
Geneva, Ala	23	7	11	26.4	8
Caryville, Fla	12	8	14	14.1	10
Conecuh:					
River Falls, Ala	35	5	10	42.0	6
Brewton, Ala	17	7	13	19.6	10
Etowah: Canton, Ga	17	30	30	17.5	30

See footnotes at end of table.

Table of flood stages during April 1937—Continued

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
EAST GULF OF MEXICO DRAINAGE—contd.					
Coosa:	*Feet*			*Feet*	
Gadsden, Ala	20	30	(1)	20.9	30
Lock No. 4, Lincoln, Ala	17	30	(1)	18.4	30
Pearl:					
Jackson, Miss	18	8	13	19.4	10
Pearl River, La	12	(3)	4	----	----
		8	15	13.6	11
MISSISSIPPI SYSTEM					
Upper Mississippi Basin					
Illinois:					
Peru, Ill	17	23	(1 5)	17.7	28
Peoria, Ill	18	27	(1)	----	----
Havana, Ill	14	21	(1)	----	----
Beardstown, Ill	14	27	(1)	----	----
Missouri Basin					
Big Sioux: Akron, Iowa	12	14	17	12.3	14, 16
Ohio Basin					
Stony Creek: Johnstown, Pa	15	26	26	17.5	26
Kiskiminetas: Saltsburg, Pa	16	26	26	16.1	26
Allegheny:					
Lock No. 8, near Mosgrove, Pa	24	26	30	28.3	26, 27
Lock No. 5, Schenley, Pa	24	26	30	34.2	26, 27
Lock No. 4, Natrona, Pa	24	26	29	31.5	27
Lock No. 3, Acmetonia, Pa	25	26	29	32.8	27
Youghiogheny:					
Confluence, Pa	13	26	26	15.0	26
Connelsville, Pa	13	26	26	15.8	26
West Newton, Pa	20	26	26	20.6	26
Monongahela:					
Lock No. 7, Greensboro, Pa	30	26	27	33.1	26
Lock No. 4, Charleroi, Pa	30	26	27	32.8	27
Muskingum: Lock No. 1, Marietta, Ohio:					
Upper Gage	28	28	30	32.0	29
Lower Gage	35	28	30	40.0	29
Scioto: La Rue, Ohio	11	26	26	11.1	26
West Fork of White:					
Anderson, Ind	8	(3)	(1 6)	10.8	6
Elliston, Ind	18	7	10	19.6	9
Edwardsport, Ind	12	7	14	17.0	11
		16	18	12.9	17
		23	27	15.0	25
		29	(1)	----	----
Wabash:					
La Fayette, Ind	11	5	10	16.8	7
		23	(1)	15.7	29
Covington, Ind	16	6	11	20.3	9
		24	(1)	19.0	30
Terre Haute, Ind	14	6	13	16.3	11
		24	(1)	15.2	27, 28
Ohio:					
Pittsburgh, Pa	25	26	29	35.1	27
Old Dam No. 2, Coraopolis, Pa	26	26	28	32.5	27
Dam No. 7, Midland, Pa	30	26	29	44.4	27
Dam No. 12, near Wheeling, W. Va	36	27	29	45.9	28
Dam No. 13, near Wheeling, W. Va	45	27	29	48.8	28
Parkersburg, W. Va	36	28	30	39.2	29
Dam No. 19, Little Hocking, Ohio	40	28	30	41.9	29
Dam No. 25, near Addison, Ohio	43	29	(1)	45.7	30
Point Pleasant, W. Va	40	29	(1)	41.7	30
Arkansas Basin					
Poteau: Potean, Okla	21	22	23	22.6	23
Red Basin					
Black: Jonesville, La	50	(3)	7	----	----
Sulphur:					
Ringo Crossing, Tex	20	4	5	21.6	4
		21	² 24	23.9	22
Naples, Tex	22	(3)	2	----	----
		24	30	25.4	26, 27
Lower Mississippi Basin					
Big Lake Outlet: Manila, Ark	10	10	17	10.4	12-14
St. Francis:					
Fisk, Mo	20	6	8	21.3	8
		25	25	20.0	25
St. Francis, Ark	18	10	15	18.8	12, 13
Yazoo: Yazoo City, Miss	29	(3)	5	----	----
Atchafalaya Basin					
Atchafalaya: Atchafalaya, La	22	(3)	7	----	----

Table of flood stages during April 1937—Continued

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
WEST GULF OF MEXICO DRAINAGE					
Rio Grande:	*Feet*			*Feet*	
Espanola, N. Mex.	7	13	(1)	7.8	17
Albuquerque, N. Mex.	4	16	17	5.0	17
GULF OF CALIFORNIA DRAINAGE					
Colorado Basin					
San Juan: Farmington, N. Mex.	7	16	17	8.0	16
PACIFIC SLOPE DRAINGE					
Columbia Basin					
Middle Fork: Eula, Oreg.	13	14	14	13.5	14
Coast Fork: Saginaw, Oreg.	9	13	16	11.5	15
McKenzie: Leaburg, Oreg.	12	13	16	15.6	14, 15
Santiam: Jefferson, Oreg.	10	13	16	14.5	15
Willamette:		[3]			
Eugene, Oreg.	12	[4] 14	16	14.3	15
Harrisburg, Oreg.	10	13	17	15.0	16
Albany, Oreg.	20	15	18	24.6	16
Salem, Oreg.	20	15	18	22.4	16
Oregon City, Oreg.	12	15	19	14.6	18

[1] Continued into May.
[2] Approximate.
[3] Continued from previous month.
[4] Fell 0.7 foot below flood stage on 5th and 0.6 foot below on 20th.
[5] Fell slightly below flood stage on 24th.
[6] Fell slightly below flood stage on 2d, 3d, and 20th.
[7] Fell slightly below flood stage on 23d.

REDETERMINATIONS AND ERRATA—MONTHLY WEATHER REVIEW, APRIL 1936

Page	Data	Published	Should be
146	Table comparing 1936 flood with previous high records:		
	1936 stage at Columbia, Va.	35.9	35.8.
	1936 stage at Hartford, Conn.	37.3	37.6.
	1936 stage at Saltsburg, Pa.	33.1	32.9.
	1936 stage at Dam No. 6, Beaver, Pa.	54.8	55.5.
146	Table of flood stages in March and April 1936:		
	Crest at Bellows Falls, Vt.	24.6	24.7.
	Date of crest at Holyoke, Mass.	Mar. 20.	Mar. 19, 20.
	Crest at Springfield, Mass.	38.6	28.6.
	Date of crest at Springfield, Mass.	do.	Mar. 20.
	Crest at Hartford, Conn.	37.3	37.6.
	Crest at Clearfield, Pa.	17.8 [1]	17.5.
	Crest at Renovo, Pa.	29.3	29.4.
	Crest at Williamsport, Pa.	33.7 [1]	33.6.
	Date of crest at Williamsport, Pa.	Mar. 19.	Mar. 18.
	Crest at Huntingdon, Pa.	22.0 [1]	22.7.
	Crest at Wilkes-Barre, Pa.	28.9	28.8.
	River for stations at Neuse and Smithfield, N. C.	Omitted	Neuse.
	Date of crest at Cheraw, S. C.	Apr. 3	Apr. 4.
147	Crest at Millstead, Ala.	42.2	42.1.
	Date of crest at Ottumwa, Iowa	Mar. 6	Mar. 5, 6.
	Crest at Saltsburg, Pa.	33.1	32.9.
	Crest at Lock No. 4, Charleroi, Pa.	40.1	40.3.
	Crest at Coshocton, Ohio, on Mar. 1 should be omitted.		
148	Oldtown (near Newport), Tenn. Insert dates above flood stage from Mar. 24 to Mar. 29—crest 11.4, date Mar. 26.		
	Crest at Oldtown (near Newport), Tenn.	12.3	10.9.
	Crest at Dam No. 6, Beaver, Pa.	54.8	55.5.
	Date of crest at Dam No. 48, Henderson, Ky.	Apr. 1	Apr. 1, 2.
	Date of crest at Dam No. 49, Uniontown, Ky.	Apr. 4	Apr. 3, 4.
	Date of crest at Cairo, Ill.	Apr. 16	Apr. 15, 16.
	Date of crest at Memphis, Tenn.	Apr. 22	Apr. 20–22.

WEATHER ON THE ATLANTIC AND PACIFIC OCEANS

[The Marine Division, I. R. TANNEHILL, in charge]

NORTH ATLANTIC OCEAN, APRIL 1937

By H. C. HUNTER

Atmospheric pressure.—Pressure averaged slightly below normal over central and southwestern portions of the North Atlantic and considerably below normal over much of the northern portion. From western Iceland to southern Greenland the average deficiency was about one-fifth of an inch. A moderate excess was found over North Sea waters and near the coast of Europe, and there was an excess likewise near Newfoundland, the Maritime Provinces, and New England.

The distribution of pressure through the month showed considerable irregularity. Among noteworthy features were the marked deficiency at Horta during the first 8 days and the moderate excess prevailing thereafter, and the excesses during the final 10 days near Newfoundland and Nova Scotia and around the British Isles.

The extremes of pressure in vessel reports at hand are 30.66 and 28.33 inches. The higher reading was noted on the Belgian motorship *Spidoleine*, during the forenoon of the 17th, near 38° N., 40° W. The lower reading was observed at mid-afternoon of the 3d, on the American steamship *Independence Hall*, when about 700 miles east by south of Cape Race.

Cyclones and gales.—April as a whole had more storm activity than is usual so late in the spring. In last month's issue it was noted that Harbour Island, in the Bahamas, had a violent storm on March 31. This probably was an early phase of the LOW, which, as April began, was central very near Bermuda, whence it moved northeastward, gaining energy, to a point near the tail of the Grand Banks early on the 2d (see chart IX). From this position it took a more eastward course, and was not far to northward of Horta at a late hour on the 3d, with decidedly less force than on the 2d. As the table of gales and storms shows, two eastbound steamships, close to 42° N., 45° W., on the 2d, encountered force-12 winds, their barometers dropping to about 28.5 inches; but, as already mentioned, a west-bound vessel near the 38th meridian noted a still lower reading the following day.

This first storm was unimportant after the 5th, and thereafter till the 12th there was no very marked storm activity except close to the American coast. Here a storm traveled northeastward near the coast line, being decidedly energetic on the 8th and 9th, close to the Middle Atlantic States, and reached the vicinity of Newfoundland the night of the 10th–11th.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, April 1937*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.62	−0.21	30.02	7	28.98	1
Reykjavik, Iceland	29.62	−.18	30.27	24	28.91	1
Lerwick, Shetland Islands	29.85	+.05	30.42	29	29.32	10
Valencia, Ireland	29.81	−.08	30.45	29	29.09	2
Lisbon, Portugal	30.09	+.10	30.36	16	29.80	12
Madeira	30.05	+.04	30.27	14	29.62	23
Horta, Azores	30.11	−.04	30.44	18, 25	29.52	3
Belle Isle, Newfoundland	29.90	+.01	30.36	4	29.02	11
Halifax, Nova Scotia	30.02	+.09	30.58	5	29.26	10
Nantucket	29.98	+.01	30.56	5	29.38	9
Hatteras	30.00	−.01	30.42	13	29.46	9
Bermuda	30.06	−.03	30.38	5	29.52	1
Turks Island	30.01	−.01	30.12	13	29.90	27
Key West	30.00	−.02	30.28	12	29.80	26
New Orleans	29.98	−.02	30.39	12	29.51	4

NOTE.—All data based on a. m. observations only, with departures compiled from best available normals related to time of observation, except Hatteras, Key West, Nantucket, and New Orleans which are 24-hour corrected means.

OCEAN GALES AND STORMS, APRIL 1937

Vessel	Voyage		Position at time of lowest barometer		Gale began April	Time of lowest barometer April	Gale ended April	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				*Inches*					
Cranford, Am. S. S.	Hamburg	Tampa	27 20 N.	62 28 W.	[1]31	7a 1	1	29.75	SSE	SW, 9	NW	WNW, 9.	S-SW-WNW.
Motocarline, Pan. M. S.	Aruba	Rotterdam	[2]45 58 N.	20 53 W.	1	5p 1	2	29.12	NW	W, 7	W	WNW, 9.	S-W.
Reiyo Maru, Jap. S. S.	Rotterdam	Philadelphia	38 40 N.	56 00 W.	1	6p 1	2	29.15	E	NNE, 8	NW	N, 9	ESE-N-NW.
Sarcoxie, Am. S. S.	Havre	New York	41 23 N.	51 00 W.	1	2a 2	2	29.22	ENE	NE, 11	N	NE, 11	ENE-N.
Express, Am. S. S.	Gibraltar	do	36 11 N.	39 10 W.	2	6p 2	4	29.45	S	SW, 11	W	W, 11	SW-W.
Montgomery City, Am. S. S.	New York	Havre	41 54 N.	45 00 W.	1	6p 2	3	28.40	ESE	N, 11	WNW	ENE, 12	ENE-NNW.
Binnendyk, Du. S. S.	Baltimore	Rotterdam	42 08 N.	45 10 W.	2	6p 2	4	[2]28.50	E	NNE, 11	NW	N, 12	E-NNE-NW.
American Farmer, Am. S. S.	London	New York	42 36 N.	45 36 W.	2	10p 2	3	28.50		WNW, 8	NNW	NNW, 10	
Gorm, Dan. S. S.	New York	Oslo	44 25 N.	46 25 W.	2	10p 2	6	29.09	NE	N, 10	NNW	N, 10	NE-NNW.
Maasdam, Du. S. S.	Rotterdam	New York	44 30 N.	39 48 W.	2	5a 3	4	[2]28.43	ESE	ENE, 7	N	NW, 9	
Exminster, Am. S. S.	New York	Casablanca	40 05 N.	31 06 W.	2	6a 3	5	[2]29.24	SSE	SSW, 9	SW	SSW, 10	SSE-SSW.
Independence Hall, Am. S. S.	Bordeaux	New York	45 30 N.	37 42 W.	2	2p, 3	5	28.33	SE	NE, 8	NNW	NNW, 9.	E-NNE.
Sarcoxie, Am. S. S.	Havre	do	41 00 N.	60 00 W.	3	6p, 3	4	29.64	E	SSW, 4	N	NE, 10	SSW-SE-NE.
Exermont, Am. S. S.	New York	Gibraltar	39 45 N.	52 00 W.	4	Noon, 4	6	29.44	E	E, 8	NW	N, 10	E-N.
Express, Am. S. S.	Gibraltar	New York	36 10 N.	42 40 W.	4	11p, 4	5	29.44	SW	W, 10	WNW	W, 11	SW-W.
San Alvaro, Br. M. S.	Ardrossan	Tampico	48 50 N.	22 20 W.	6	8p, 6	8	29.02	S	SSW, 8	SW	SSW, 9	SSW-WSW.
Betterton, Am. S. S.	New York	Houston	33 50 N.	75 15 W.	5	10p, 6	7	29.77	SE	S, 6	NW	SSE, 9	SE-WNW.
San Jose, Am. S. S.	do	Tampa	34 00 N.	77 00 W.	8	8p, 8	8	29.62	SW	SW, 9	WSW	WSW, 10	SSE-WSW.
Texan, Am. S. S.	do	Cristobal	36 31 N.	73 53 W.	9	4p, 9	10	29.46	SW	SW, 7	W	W, 9	SW-WSW.
American Banker, Am. S. S.	Plymouth	Boston	42 12 N.	45 54 W.	10	7p, 10	11	29.41	SSW	SW, 4	W	WSW, 9	SSW-WSW.
Black Condor, Am. S. S.	Antwerp	New York	47 50 N.	33 10 W.	12	2p, 12	13	29.53	SW	WSW, 9	WNW	W, 10	SW-W.
Black Tern, Am. S. S.	Rotterdam	Boston	42 54 N.	52 46 W.	13	3p, 13	13	29.52	NE	NE, 8	WNW	NNE, 9	NE-NW.
Ohio Maru, Jap. S. S.	do	Baltimore	49 30 N.	21 25 W.	14	6a, 15	16	29.26	SSE	SW, 7	N	W, 11	SSE-SW-NW.
West Kyska, Am. S. S.	London	Dalhousie	50 10 N.	21 30 W.	15	8a, 15	16	29.42	W	W, 7	NW	W, 10	WSW-W.
Sundance, Am. S. S.	Bremen	Charleston	49 53 N.	15 33 W.	15	Noon, 15	16	29.51	SSW	SSW, 7	NW	WNW, 10	SSW-W.
San Alvaro, Br. M. S.	Ardrossan	Tampico	28 16 N.	67 05 W.	16	11a, 16	16	29.67	S	SSW, 9	WNW	SSW, 9	SSE-WSW.
Bayano, Br. S. S.	Bermuda	Jamaica	30 52 N.	65 31 W.	16	6p, 16	16	29.50	SE	S, 12	SW	S, 12	SE-SW.
Fairfield City, Am. S. S.	Gibraltar	Savannah	38 53 N.	55 40 W.	16	4a, 18	18	30.04	S	S, 8	SSE	S, 10	S-SSE.
Tennessee, Dan. S. S.	Gotheburg	New York	54 30 N.	35 55 W.	17	7a, 18	19	29.54	S	W, 9	W	WNW, 9.	W-NW.
Black Hawk, Am. S. S.	Antwerp	do	45 32 N.	40 57 W.	21	4p, 22	23	29.35	S	S, 3	NNW	N, 9	S-NNE.
American Merchant, Am. S. S.	London	do	43 54 N.	41 42 W.	21	8p, 22	23	29.15	SSW	NNE, 9	NW	N, 10	WSW-NNE-N.
Europa, Ger. S. S.	Cherbourg	do	46 18 N.	32 48 W.	23	6p, 23	23	[2]28.96	SSE	WNW, 9	W	WNW, 10	
Sundance, Am. S. S.	Bremen	Charleston	41 15 N.	52 38 W.	22	10p, 23	25	29.60	N	SW, 6	NNW	NNE, 10.	SSE-SW-N.
Montreal City, Br. S. S.	Bristol	Norfolk	49 23 N.	30 17 W.	22	Mdt, 23	26	29.00	S	W, 8	S	SW, 10	S-W.
West Chatala, Am. S. S.	Houston	Liverpool	39 40 N.	55 00 W.	22	3a, 24	25	29.42	SE	NE, 7	N	S, 10	NNE-NE-N.
Normandie, Fr. S. S.	Havre	New York	[2]42 56 N.	44 01 W.	24	Noon, 24	25	29.17	S	S, 9	NNE	S, 9	SE-SW-NNE.
Nishmaha, Am. S. S.	New Orleans	London	40 10 N.	48 50 W.	23	Noon, 25	25	29.42	SSE	NE, 8	NW	NE, 9	NE-NW.
Royal Arrow, Am. S. S.	New York	Beaumont	35 23 N.	75 00 W.	25	4a, 26	26	29.37	E	ESE, 8	W	ESE, 10	E-S-W.
Nagara Mary, Jap. M. S.	do	Cristobal	34 32 N.	73 40 W.	25	6a, 26	26	29.45	SE	SSE, 9	W	SSE, 9	SSE-S-W.
San Juan, Am. S. S.	San Juan	New York	37 17 N.	73 06 W.	26	4p, 26	26	29.60	SE	SE, 9	SE	SE, 9	SE-SSW.
Frode, Dan. S. S.	Danzig	do	49 50 N.	39 40 W.	30	3p, 30	[4]1	[2]29.92	SSW	WSW, —	NW	SW, 9	S-W.
NORTH PACIFIC OCEAN													
Nojima Maru, Jap. S. S.	Yokohama	Los Angeles	45 30 N.	174 00 E.	[1]31	Mdt. 31	1	29.03	W	W, 8	WSW	WSW, 9.	
Pres. Jefferson, Am. S. S.	Victoria, B. C.	Yokohama	51 45 N.	173 05 W.	1	Noon, 2	2	28.88	SSW	SW, 8	SW	SW, 9	SW-W.
Toorak, Br. S. S.	Osaka	Los Angeles	40 49 N.	174 28 E.	4	2a, 5	5	29.23	SSE	SSE, 9	NNW	NNE, 10.	SSE-WSW.
Fujisan Maru, Jap. M. S.	Tokuyama	do	42 47 N.	168 10 W.	5	7a, 5	6	29.22	WNW	W, 6	NW	WNW, 10	SW-WNW.
Athelking, Br. M. S.	San Francisco	Yokohama	34 04 N.	146 55 E.	5	10a, 5	6	29.49	S	SW, 8	W	SW, 8	S-W.
Omrosan Maru, Jap. M. S.	Tama, Japan	Los Angeles	41 36 N.	156 11 W.	5	Mdt. 5	7	[2]29.02	WSW	W, 9	NW	W, 9	WSW-NW.
Siantar, Du. M. S.	Manila	do	39 06 N.	155 55 E.	5	1a, 6	8	29.24	SE	WSW, 6	W	SE, 8	SE-S-WSW.
Pres. Jefferson, Am. S. S.	Victoria, B. C.	Yokohama	45 06 N.	156 26 E.	6	8p, 6	7	28.63	E	S, 9	WNW	S, 9	S-W.
Pres. Grant, Am. S. S.	Yokohama	Seattle	4b 30 N.	163 02 E.	5	6p, 7	7	28.91	SSE	SW, 8	WSW	ESE, 10.	SW-W.
Toorak, Br. S. S.	Osaka	Los Angeles	[2]42 10 N.	166 06 W.	6	——, 7	8	29.62	S	W, 7	WNW	W, 9	
Hanover, Am. S. S.	Nasugbu, P. I.	do	44 01 N.	166 33 E.	7	Noon, 7	8	29.33	SW	SW, 8	WNW	SW, 9	
Tokai Maru, Jap. M. S.	Yokohama	San Francisco	45 37 N.	145 49 W.	6	6a, 8	9	29.29	NW	SW, 8	W	SW, 8	NW-SW.
Pres. Jefferson, Am. S. S.	Victoria, B. C.	Yokohama	40 03 N.	147 06 E.	8	8a, 8	8	29.62	W	NW, 9	NW	NW, 9	W-NW.
Kyokuto Maru, Jap. M. S.	Tokuyama	San Francisco	36 57 N.	146 51 E.	9	4a, 10	10	29.33	ENE	NNE, 8	N	NE, 9	NE-N.
Chichibu Maru, Jap. M. S.	Yokohama	Honolulu	35 02 N.	149 50 E.	8	3a, 10	11	29.15	E	S, 7	W	WSW, 11	S-WSW.
San Pedro Maru, Jap. M. S.	do	Los Angeles	40 54 N.	158 02 E.	10	Mdt. 10	11	29.19	E	NNE, 10	N	NNE, 10.	NE-N.
Tai Shan, Pan. M. S.	do	San Francisco	43 25 N.	137 10 W.	10	2a, 11	11	29.63	SSW	SSW, 9	SSW	SSW, 9	
Maliko, Am. S. S.	Seattle	Honolulu	47 07 N.	127 32 W.	11	10p, 11	11	29.64	SE	S, 8	S	SE, 8	SE-SW.
Pres. McKinley, Am. S. S.	Victoria, B. C.	Yokohama	51 48 N.	143 00 W.	11	Mdt. 12	11	28.94	SE	SSE, 3	SSE	SSE, 10	SSE-SW.
Toorak, Br. S. S.	Osaka	Los Angeles	41 00 N.	136 10 W.	12	6a, 12	12	29 16	S	S, 7	SW	SW, 10	S-SW.
Maliko, Am. S. S.	Seattle	Honolulu	45 00 N.	131 48 W.	12	5p, 12	13	29.04	SE	SW, 9	W	SW, 9	ESE-SSW-W.
Tai Shan, Pan. M. S.	Yokohama	San Francisco	[2]39 12 N.	124 10 W.	12	6p, 12	12	29.82	SSW	SSW, 8		SSW, 8	None.
Mana, Am. S. S.	Portland, Oreg.	Honolulu	43 20 N.	130 25 W.	11	2p, 12	15	29.31	SSE	SSW, 7	NNW	SSW, 8	SSE-W.
Maliko, Am. S. S.	Seattle	do	42 46 N.	134 50 W.	13	7p, 13	13	29.41	SW	SW, 6	SW	SW, 8	
Winamac, Br. S. S.	Yokohama	Los Angeles	40 07 N.	156 17 W.	15	4p, 15	15	29.74	S	SSE, 10	NW	SSE, 10	SE-W.
General Lee, Am. S. S.	Portland, Oreg.	Yokohama	48 35 N.	169 27 E.	15	Noon, 16	17	29.68	SW	WSW, 8	WNW	WSW, 8.	
Pres. McKinley, Am. S. S.	Victoria, B. C.	do	47 56 N.	164 51 E.	19	2p, 19	19	30.04	S	WNW, 5	WNW	SSE, 9	S-WNW.
Athelking, Br. M. S.	Yokohama	San Francisco	40 30 N.	170 16 W.	19	4p, 20	20	29.53	NE	NNE, 6	NNE	NNE, 9	
Ogura Maru, Jap. M. S.	do	Los Angeles	34 12 N.	120 12 W.	22	4a, 23	22	29.95	N	NW, 2	NW	NNW, 8.	NW-SW.
Express of Japan, Br. S. S.	do	Honolulu	[2]34 54 N.	140 35 E.	23	8a, 23	23	30.13	NE	NNE, 7	NE	NE, 8	NNE-NE.
Irisbank, Br. M. S.	Balboa	Los Angeles	14 15 N.	95 20 W.	25	4a, 26	26	29.90	NNW	NNW, 8	N	NNW, 8.	
Thames Maru, Jap. S. S.	Yokohama	Vancouver, B. C.	49 29 N.	136 10 W.	28	8p, 28	29	29.43	S	SW, 8	SW	SW, 8	S-WSW.
Illinois, Am. S. S.	Manila	San Francisco	46 38 N.	152 28 W.	28	4a, 30	30	30.04	NW	NNW, 6	N	NNW, 8.	

[1]March. [2]Barometer uncorrected. [3]Position approximate. [4]May.

Between Turks Island and Bermuda a LOW developed on the 15th or early on the 16th, and was of comparatively small size for a while but, for the latitude and the time of year, of unusual energy. The British steamer *Bayano*, bound southwestward from Bermuda, had a brief but strenuous encounter with this storm for 3 hours late on the afternoon of the 16th; the greatest force of wind was judged to be 12, this being the third and final report of force 12 from the North Atlantic this month. The further progress of this storm was nearly due northward and late on the 17th it was close to Nova Scotia.

During the final decade of April there was moderate storm activity over and around the Grand Banks and also to eastward near midocean on several days. Close to the American coast there was noteworthy turbulence on the 26th, mainly between Cape Hatteras and Cape May. The LOW concerned had been central near Savannah early on the 25th, with moderate strength, then gained in energy as it took its northeasterly course, finally losing force somewhat on the 27th, as it moved northward and inland.

Fog.—Over and near the Grand Banks and thence westward to the coast of Nova Scotia, fog was of rather frequent occurrence, especially during the period from the 15th to 22d. There was, however, somewhat less fog here than is expected in April. The 5°-square, 40° to 45° N., 45° to 50° W., is reported to have had fog on 9 days.

Greater amounts, in fact the greatest anywhere in North Atlantic waters, were noted near New England, where the square 40° to 45° N., 65° to 70° W., experienced 11 days with fog. Here and to southwestward as far as Hatteras fog was more common than is usual during April.

To southward of Hatteras, as far as southeastern Florida, no fog was noted near the American coast. In the Gulf of Mexico, on the other hand, there was greater frequency than is usual as late as April, especially near the northwestern shore. Two tankers collided early on the 8th, 300 miles off Sabine Pass, because of dense fog; each was somewhat damaged, but was able to make port unassisted.

In comparison with March just preceding, fog decreased in the Gulf of Mexico, but increased in almost every square from Hatteras to beyond the Grand Banks.

From the forty-fifth meridian to the immediate vicinity of the British Isles fog was even more infrequent than usual; some squares along the chief steamship lanes have failed to furnish a single report. The waters around Ireland and England, however, had considerable fog, chiefly during the period from the 4th to 11th.

NORTH PACIFIC OCEAN, APRIL 1937

By WILLIS E. HURD

Atmospheric pressure.—Pressure changes over the North Pacific Ocean during April 1937 were unimportant as compared with the normals of the month, except in Alaskan waters. From Dutch Harbor, with an average pressure of 29.88 (0.10 above the normal), to Juneau, average 29.73 (0.23 below the normal), the range of departure from normal was considerable. Between these two stations, Kodiak had the lowest average pressure, 29.70, shown for North Pacific island stations during the month. The average center of the Aleutian LOW was situated over and near the Gulf of Alaska.

In middle latitudes high pressure prevailed with little intermission from the California coast westward almost to Japan. In the region of the Aleutian Islands the barometer remained high from the 18th to the 30th.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean, April 1937 at selected stations*

Station	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Point Barrow	29.92	−0.17	30.46	22	29.50	25
Dutch Harbor	29.88	+.10	30.64	30	28.94	3
St. Paul	29.86	+.07	30.68	29	28.80	3
Kodiak	29.70	−.05	30.42	24	29.32	1
Juneau	29.73	−.23	30.20	24	29.25	4
Tatoosh Island	29.98	−.02	30.38	16	29.19	12
San Francisco	30.08	+.03	30.27	4	29.76	26
Mazatlan	29.88	−.01	29.96	2, 3	29.78	21
Honolulu	30.05	−.01	30.18	4	29.89	29
Midway Island	30.11	−.01	30.28	5	29.60	23
Guam	29.85	−.04	29.92	1, 2, 6	29.77	25, 26
Manila	29.84	+.02	29.89	20	29.77	4
Hong Kong	29.89	−.01	30.00	5	29.78	12
Nemuro	30.02	+.06	30.42	12	29.44	5

NOTE.—Data based on 1 daily observation only, except those for Juneau, Tatoosh Island, San Francisco, and Honolulu, which are based on 2 observations. Departures are computed from best available normals related to time of observation.

Cyclones and gales.—Cyclonic conditions, except during the first 10 days of April, were far less vigorous than in March, and after the middle of the month declined appreciably in intensity. Following the 20th no accompanying gales in excess of force 8 are at this writing of known record for any part of the ocean. The last gale of force as high as 10 occurred on the 15th, near 40° N., 156° W., barometer 29.74, encountered by the British steamship *Winamac*. The only gale of the month reported as of force 11 was experienced on the 10th by the Japanese motorship *Chichibu Maru*, barometer 29.15, in 35°02′ N., 149°50′ E. Anticyclones persisted over central waters of the ocean, while the cyclones of the month mostly traversed higher latitudes. In consequence, few gales occurred to the southward of the 40th parallel, except to the eastward of Japan where high winds occurred on several days between latitudes 30° and 40° N.

Some cyclones originated this month in far eastern waters and proceeded thence northeastward toward the Aleutians; the two principal disturbances, both originating south of Honshu, were those of the 4th to 7th and the 8th to 10th. The earlier proceeded into the Bering Sea; the later dissipated southwest of the Aleutians. Practically all the stormy weather of the month between Japan and longitude 165° E., including the gales of force 8 to 11 occurring on the 5th to 10th, resulted from the activities of these cyclones. In connection with the earlier cyclone, the American steamship *President Jefferson* had the lowest reported barometer of the month on the North Pacific, 28.63 inches, with a south wind of force 9, in 45°06′ N., 156°26′ E.

During the 1st to 3d the Aleutian LOW attained considerable depth over the southeastern Bering Sea and adjacent Pacific waters, the central pressures being below 29 inches. As a result of this disturbed condition, fresh to strong gales were experienced on the 1st and 2d by ships to the southward of the Aleutians.

Along the eastern half of the middle and northern routes, while some scattered fresh gales occurred late in the month, most of the high wind velocities reported were experienced between the 1st and 15th, inclusive. Of these the most important, of force 10, were encountered by the following ships: The Japanese steamship *Fujisan Maru*, on the 5th, near 43° N., 168° W.; the American steamship *President McKinley*, on the 11th, near 52° N., 143° W.; the British steamship *Toorak*, on the 12th, near 41° N., 136° W.; and the British steamship *Winamac*, on the 15th, near 40° N., 156° W.

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The period 11th to 13th showed the most widespread storminess of the month in west longitudes, to the eastward of the one hundred and forty-fifth meridian, between 40° and 52° north latitude. During this period whole gales were experienced locally a day or two out from the American coast; near the coast fresh gales were met on the 11th southwest of Tatoosh Island, and on the 12th a short distance north of San Francisco. A further coastal gale was that of the 22d, off Point Conception.

In tropical waters the only gale of the month reported was a Tehuantepecer of force 8 which occurred on the 26th.

Fog.—Along the routes north of the fortieth parallel, between 145° W. and 145° E., fog has shown a marked increase in frequency since March. Although fog appears not to have formed over individual 5° ocean regions on more than 2 to 4 days each, yet throughout the area as a whole fog was observed daily from April 16 to 30. Between 29° and 35° N., 165° W. and 165° E. there were 8 days with fog, an unusual number at any season on this part of the ocean. In American coastal waters there was 1 day reported with fog off Washington; there were 4 days, off California; and 7 days, off Lower California.

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

TABLE 1.—*Condensed climatological summary of temperature and precipitation by sections, April 1937*

[For description of tables and charts, see REVIEW, January, p. 35]

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	63.4	−0.2	2 stations	92	[1] 19	2 stations	29	[1] 1	7.03	+2.53	Fairhope	18.30	Demopolis	2.94
Arizona	58.7	−1.4	Agua Caliente	105	15	Bright Angel	10	7	.10	−.49	Bright Angel	.01	43 stations	.00
Arkansas	61.7	+.2	Newport	96	17	Gilbert	20	6	3.18	−1.63	St. Francis	6.23	Monticello [2]	1.30
California	53.5	−2.7	2 stations	101	15	Soda Springs	2	23	1.42	−.22	Crescent City (near)	16.76	10 stations	.00
Colorado	43.9	+.2	Las Animas	95	16	Pearl	−12	9	.99	−.76	Westcliffe	3.63	Ignacio	.01
Florida	68.9	−.9	Bushnell	94	29	Garniers (near)	36	1	4.98	+2.09	Pensacola	17.03	Key West	.13
Georgia	62.0	−1.3	3 stations	93	[1] 19	2 stations	24	12	6.96	+3.17	Canton	10.23	Savannah No. 1	4.15
Idaho	41.7	−3.3	Indian Cove	87	26	Blackfoot Dam	−6	6	2.44	+1.02	Deception Creek	8.54	Mackay	.09
Illinois	51.6	−.5	5 stations	91	[1] 17	2 stations	23	[1] 10	4.82	+1.42	Mount Vernon	7.74	Keithsburg	2.40
Indiana	51.2	−.6	Elliston	93	17	3 stations	23	[1] 11	5.00	+1.48	Frankfort	7.47	Vevay	2.64
Iowa	47.7	−1.0	Omaha, Nebr	85	22	Inwood (near)	20	8	3.20	+.49	Grundy Center	4.88	Thurman	1.45
Kansas	54.3	−.4	Ashland	98	16	Oberlin	15	5	1.00	−1.53	Independence	4.42	Johnson	.03
Kentucky	55.9	−.2	3 stations	91	[1] 17	Farmers	22	12	4.38	+.40	Paducah	6.21	Grant	2.51
Louisiana	66.5	−.6	Urania	91	30	4 stations	32	[1] 1	3.44	−1.18	New Orleans	7.42	Grand Coteau	.44
Maryland-Delaware	51.2	−.9	2 stations	94	18	Oakland, Md	19	1	6.38	+2.93	Clear Springs, Md	12.99	Delaware Breakwater, Del.	3.59
Michigan	41.5	−1.2	Saranac	80	29	Sidnaw	−1	3	3.73	+1.27	Ganges	8.18	Calumet	1.09
Minnesota	40.7	−2.3	3 stations	76	[1] 19	2 stations	4	[1] 1	3.82	+1.73	Wheaton	6.33	Farmington	1.51
Mississippi	64.8	+.2	2 stations	94	17	do	30	[1] 1	4.08	−.75	Fruitland Park	9.54	Stoneville	.91
Missouri	54.5	−.7	3 stations	93	17	Licking (near)	21	[1] 6	4.04	+.13	Lockwood	7.95	Macon	1.23
Montana	42.5	−.4	Garland	85	15	Hebgen Dam	−2	3	.92	−.21	Heron	4.34	Choteau	.05
Nebraska	48.2	−1.0	Franklin	94	22	Hyannis	11	9	1.15	−1.22	Westpoint	3.82	Sidney	.11
Nevada	47.5	−.4	Logandale	94	15	San Jacinto	12	[1] 10	.48	−.28	Lamoille	2.00	3 stations	.00
New England	43.0	−.7	3 stations	76	[1] 15	First Conn. Lake, N. H.	−4	1	3.88	+.54	Gloucester, Mass	7.25	Squa Pan Dam, Maine.	.63
New Jersey	49.3	−.4	2 stations	85	18	Runyon	16	1	4.64	+1.03	Freehold	5.79	Newton	3.05
New Mexico	51.6	.0	Portales	98	18	Selsor Ranch	−2	5	.39	−.48	Corona	1.85	29 stations	.00
New York	43.5	−.7	Port Jervis	78	18	Stillwater Reservoir	1	1	3.59	+.60	Fredonia	7.10	Gabriels	7.14
North Carolina	57.7	−.1	Shelby	92	18	Mount Mitchell	13	12	5.86	+2.25	Swansboro	14.90	Marshall	3.24
North Dakota	40.7	−.7	2 stations	79	[1] 15	Parshall	3	3	2.02	+.59	2 stations	5.53	Crosby	.32
Ohio	49.7	.0	Portsmouth	90	23	2 stations	20	12	3.95	+.82	Napoleon	6.05	Waverly	2.21
Oklahoma	60.9	+.6	5 stations	97	16	do	21	5	2.30	−1.03	Antlers	5.85	Hooker	T
Oregon	43.8	−3.3	Oakridge	86	27	Austin	1	11	4.13	+2.11	Valsetz	18.54	Warmspring Reservoir.	.53
Pennsylvania	47.7	−.9	Arendtsville	89	18	6 stations	19	[1] 1	5.53	+2.09	Arendtsville	9.49	Gratersford	2.78
South Carolina	61.0	−1.3	3 stations	91	23	Long Creek (near)	23	12	6.66	+3.49	Dillon	12.16	Gaston Shoals	3.42
South Dakota	43.8	−1.9	Hot Springs	88	15	Camp Crook	−4	4	1.69	−.36	Sisseton	5.54	Dowling	.17
Tennessee	58.3	−.3	2 stations	91	[1] 17	Rugby	22	12	4.26	−.17	Sewanee	7.36	Moscow	1.55
Texas	66.3	+.2	do	112	28	Pampa	20	5	1.04	−1.99	Wiergate	6.11	3 stations	.00
Utah	44.8	−2.2	Hanksville	90	[1] 14	Silver Lake	−1	8	.92	−.26	Silver Lake	4.04	4 stations	.00
Virginia	54.1	−.3	2 stations	95	[1] 18	Mountain Lake	20	17	5.98	+2.62	Big Meadow	13.65	Floyd	2.16
Washington	46.0	−2.0	Kiona	88	14	Bumping Lake	9	6	5.13	+2.65	Big Four	19.68	Hanford	.73
West Virginia	51.4	−.3	Romney	91	18	Rainelle	18	[1] 1	4.09	+.57	Harper's Ferry	8.76	Dam No. 19 O. R.	1.98
Wisconsin	41.7	−1.9	Darlington	83	24	Long Lake	5	3	3.35	+.82	Manitowoc	5.56	Plum Island	1.23
Wyoming	39.3	−.8	2 stations	85	15	Moran	−10	12	1.49	−.08	Dome Lake	5.70	Deaver	.01
Alaska [March]	12.8	−2.3	Craig	62	12	Kotzebue	−48	9	1.51	−.67	Little Portwalter	21.26	2 stations	.00
Hawaii	70.9	+1.0	Mana Pump	90	15	Kanalohuluhulu	45	13	6.63	−1.93	Puohakamoa No. 2	25.60	Kaanapali	.12
Puerto Rico	75.0	.0	2 stations	94	[1] 3	3 stations	54	[1] 1	4.84	+.53	Orocovis (Barros)	13.24	Bayamon	.77

[1] Other dates also.

[2] Soil erosion station.

TABLE 2.—*Climatological data for Weather Bureau stations, April 1937*

[Compiled by Annie E. Small by official authority, U. S. Weather Bureau]

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max + mean min ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch, or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
New England							43.8	−0.1										72	3.98	+1.0										6.2		
Eastport	76	67	85	29.94	30.02	+0.09	40.7	+1.7	62	26	47	28	4	34	27	37	34	82	1.75	−1.1	10	10.8	sw.	40	e.	22	8	6	16	6.1	1.6	0.0
Greenville, Maine	1,070	6	40	28.85	30.04	.....	38.0	.....	69	27	49	10	4	27	41	33	26	...	2.02	.....	10	5.3	n.	17	.....	20	11	4	15	.....	12.8	.0
Portland, Maine	103	82	117	29.90	30.03	+.07	43.4	+.4	66	14	50	28	4	36	25	38	31	67	5.75	+2.4	14	9.3	n.	27	ne.	22	10	9	11	5.5	5.7	.0
Concord	289	60	.....	29.69	30.01	+.02	43.1	−.3	66	30	52	26	13	34	37	...	...	...	3.86	+1.1	12	.....	nw.	.....	.....	.....	9	5	16	.....	9.4	.0
Burlington	403	11	48	29.56	30.01	+.02	41.7	−1.6	66	29	50	16	1	33	28	37	32	71	1.33	−.8	14	9.2	nw.	29	s.	5	7	5	18	6.5	1.7	.0
Northfield	876	12	60	29.07	30.04	+.05	38.6	−1.7	65	30	49	10	3	28	39	35	29	70	1.97	−.3	14	7.3	s.	27	s.	6	6	6	18	6.7	5.8	.0
Boston [1]	29	31	50	29.98	30.00	+.03	45.2	−1.2	71	14	52	31	1	38	26	40	34	70	5.34	+2.0	13	11.7	nw.	42	e.	22	7	6	17	6.8	T	.0
Nantucket	12	14	90	29.98	29.99	+.02	43.9	+.5	60	20	49	32	5	39	20	40	37	80	5.29	+2.3	17	16.3	ne.	45	e.	22	11	6	13	5.6	T	.0
Block Island	26	11	46	29.98	30.01	+.03	44.4	+.4	60	19	50	34	1	39	16	41	39	84	4.59	+1.1	14	16.4	e.	42	e.	22	5	12	13	6.5	T	.0
Providence	160	215	251	29.83	30.01	+.03	46.4	−.2	71	14	55	30	4	38	28	40	33	66	5.27	+2.1	13	12.1	nw.	32	nw.	20	9	9	12	6.0	T	.0
Hartford	159	70	104	29.83	30.01	+.02	47.1	+.4	71	14	56	29	4	38	28	39	32	66	3.90	+.5	11	9.3	n.	26	ne.	29	7	11	12	6.0	.9	.0
New Haven	106	74	153	29.90	30.02	+.03	47.3	+.1	70	14	55	32	3	40	25	41	33	61	4.75	+1.2	13	10.4	n.	33	n.	29	6	11	13	6.4	T	.0
Middle Atlantic States							51.1	−0.3										65	4.64	+1.6										6.3		
Albany	97	97	112	29.91	30.02	+.02	46.2	−.6	72	14	55	26	1	37	32	40	32	61	1.89	−.6	15	8.0	s.	24	se.	26	7	8	15	6.8	.1	.0
Binghamton	871	57	79	29.05	29.99	−.03	45.0	−.4	71	30	54	27	1	36	33	...	...	...	3.58	+1.1	19	7.9	nw.	24	se.	22	4	6	20	7.8	.7	.0
New York	314	415	454	29.66	30.00	.00	49.0	−.4	70	6	56	33	11	42	22	42	34	61	5.00	+1.8	14	15.8	n.	46	se.	6	7	9	14	6.1	T	.0
Harrisburg	374	94	104	29.58	29.99	−.03	49.6	−1.3	84	18	58	33	1	42	40	42	34	60	4.58	+1.9	14	9.2	nw.	28	sw.	14	5	14	11	6.4	T	.0
Philadelphia	114	174	367	29.88	30.01	.00	51.2	−.9	80	18	59	35	11	43	37	43	35	61	4.38	+1.3	14	15.2	nw.	40	s.	6	5	11	14	6.4	T	.0
Reading	323	283	306	29.64	30.00	.....	49.8	−.5	83	18	58	33	11	42	37	42	34	60	3.24	−.0	13	15.0	nw.	43	se.	21	5	12	13	6.6	T	.0
Scranton	805	72	104	29.13	30.00	−.01	46.8	−1.3	79	18	56	28	1	38	34	40	33	65	3.51	+.7	14	8.0	nw.	30	nw.	18	5	10	15	6.5	.1	.0
Atlantic City	52	37	172	29.94	30.00	.00	49.6	+1.8	73	20	56	34	12	44	23	44	39	74	4.22	+1.2	13	19.0	e.	57	e.	26	6	9	15	6.8	.0	.0
Sandy Hook	22	10	57	29.97	29.99	.....	48.8	+.5	67	14	54	35	11	43	20	43	38	73	3.75	+.1	14	15.8	ne.	42	s.	6	7	11	12	6.1	.0	.0
Trenton	190	88	106	29.79	30.00	.....	50.0	+.2	79	18	58	32	11	42	37	43	37	67	4.31	+1.4	15	11.9	n.	30	ne.	26	8	8	14	6.2	T	.0
Baltimore	123	100	215	29.86	29.99	−.02	53.2	−.4	84	18	61	34	11	45	37	45	38	61	7.92	+4.6	13	13.5	ne.	43	ne.	26	6	10	14	6.4	T	.0
Washington	112	62	85	29.86	29.98	−.04	53.4	+.1	93	18	62	34	12	44	45	45	37	61	6.85	+3.6	12	9.2	nw.	24	e.	26	7	12	11	6.0	T	.0
Cape Henry	18	8	54	29.96	29.98	.....	55.6	+1.0	87	18	63	38	1	48	41	50	46	74	5.34	+2.0	13	14.0	sw.	38	e.	25	11	8	11	5.4	.0	.0
Lynchburg	686	148	184	29.24	29.99	−.03	56.0	−1.3	92	18	67	32	11	45	41	48	41	65	5.97	+2.1	11	8.8	nw.	26	nw.	2	11	9	10	5.1	T	.0
Norfolk	91	80	125	29.90	30.00	−.01	57.0	+.2	90	18	66	40	12	48	44	50	44	67	6.44	+3.2	12	12.4	sw.	35	se.	26	10	6	14	5.9	.0	.0
Richmond	144	11	52	29.83	29.99	−.03	56.4	−.2	91	18	67	34	11	46	45	48	41	63	6.02	+2.5	12	9.4	sw.	34	sw.	22	10	8	12	5.9	.0	.0
Wytheville	2,304	49	55	.....	29.98	−.05	51.1	−.9	83	23	62	29	17	40	46	...	...	66	2.80	−.2	14	8.2	w.	29	s.	5	9	8	13	.....	T	.0
South Atlantic States							61.7	−0.2										71	5.69	+2.7										4.6		
Asheville	2,253	89	104	27.63	29.98	−.05	54.2	+.3	84	18	66	30	12	43	50	46	39	65	3.51	+.5	10	9.7	nw.	31	e.	29	8	10	12	5.8	T	.0
Charlotte	779	63	86	29.15	29.99	−.04	59.2	−.6	88	23	69	35	12	49	34	50	43	62	6.13	+2.8	11	8.3	sw.	25	sw.	27	13	6	11	4.8	.0	.0
Greensboro [1]	886	6	56	29.02	29.98	.....	55.6	.....	88	18	67	29	11	44	39	48	43	70	4.94	.....	10	9.6	sw.	38	e.	24	11	6	13	5.5	.0	.0
Hatteras	11	5	50	.....	30.00	−.01	59.6	−.2	75	27	65	42	13	54	23	...	...	79	6.42	+2.9	11	16.1	sw.	42	se.	25	13	9	8	.....	.0	.0
Raleigh	376	103	146	29.56	29.97	−.06	60.0	+.6	89	18	70	37	12	50	34	53	49	75	6.26	+2.8	13	10.0	sw.	26	se.	25	13	9	8	4.7	.0	.0
Wilmington	72	73	107	29.92	29.99	−.04	62.5	+.5	82	23	71	39	12	54	30	56	52	74	6.74	+4.1	11	11.5	sw.	30	sw.	18	17	3	10	4.3	.0	.0
Charleston	48	11	92	29.95	30.00	−.03	64.6	+.1	85	22	73	45	12	56	26	58	54	74	6.55	+4.0	11	10.9	sw.	33	n.	18	17	5	8	3.9	.0	.0
Columbia, S. C	347	70	91	29.62	30.00	−.03	62.4	−.9	89	19	73	35	12	52	33	54	48	66	6.48	+3.6	9	9.1	s.	26	sw.	27	16	6	8	4.0	.0	.0
Greenville, S. C	1,039	139	.....	.....	.....	.....	58.6	.0	86	19	69	36	11	48	34	...	...	...	4.57	+.8	10	.....	sw.	.....	.....	.....	16	5	9	.....	.0	.0
Augusta	182	62	77	29.78	29.98	−.05	63.1	−1.1	89	19	74	36	13	52	35	55	48	67	7.75	+4.7	11	6.2	nw.	20	sw.	21	14	7	9	4.5	.0	.0
Savannah	65	73	152	29.93	30.00	−.03	66.0	.0	91	19	74	44	12	56	32	58	54	74	4.15	+1.6	8	11.4	s.	41	se.	4	16	7	7	3.7	.0	.0
Jacksonville	43	86	110	29.97	30.02	−.02	68.3	−.4	88	22	78	46	13	59	29	60	56	73	4.01	+1.6	9	8.6	sw.	25	w.	9	13	7	10	4.4	.0	.0
Florida Peninsula							72.6	+0.2										73	1.83	−0.3										5.2		
Key West	22	10	64	29.98	30.00	−.02	76.8	+1.1	88	9	82	62	1	71	18	69	66	75	.13	−1.2	3	10.2	se.	25	w.	9	12	11	7	4.7	.0	.0
Miami	25	124	168	29.99	30.02	−.01	74.1	+1.3	86	30	80	57	10	68	22	67	63	71	1.60	−1.5	9	10.6	se.	31	sw.	9	4	14	12	6.2	.0	.0
Tampa	35	88	197	29.98	30.02	−.04	70.5	−.4	88	23	79	50	11	62	25	63	59	74	3.75	+1.7	8	11.0	s.	29	nw.	8	11	12	7	4.7	.0	.0
Titusville	43	5	36	29.96	30.01	.....	68.9	−1.4	90	22	80	45	1	57	32	63	60	...	1.83	−.2	9	.....	se.	.....	.....	.....	10	6	14	.....	.0	.0
East Gulf States							65.5	−0.2										70	7.26	+3.1										4.5		
Atlanta [1]	976	5	53	28.95	29.97	−.06	59.7	−1.3	87	18	71	36	7	48	38	51	44	64	5.61	+5.0	11	9.4	nw.	31	se.	4	14	5	11	4.7	.0	.0
Macon	370	79	87	29.59	29.98	−.05	62.6	−1.3	89	19	74	35	12	51	34	54	48	64	6.68	+3.5	10	6.3	s.	25	ne.	29	15	7	8	4.2	.0	.0
Thomasville	273	49	58	29.71	30.01	−.02	65.8	−.9	86	20	76	42	7	55	32	59	56	...	6.22	+2.9	11	.....	sw.	.....	.....	.....	16	5	9	.....	.0	.0
Apalachicola	35	11	.....	29.97	30.01	.....	66.2	−.8	85	16	73	49	7	60	21	61	58	79	7.18	+4.4	7	8.8	s.	26	e.	30	11	8	11	5.2	.0	.0
Pensacola	56	149	185	29.94	30.00	−.02	65.9	−.8	85	16	72	47	10	60	19	62	59	82	17.03	+13.0	9	13.0	s.	51	se.	30	17	6	7	4.2	.0	.0
Anniston	741	9	.....	.....	.....	.....	61.6	+1.2	87	20	75	32	7	49	40	...	...	...	7.64	+3.3	9	.....	w.	.....	.....	.....	14	7	9	.....	.0	.0
Birmingham	700	11	48	29.20	29.98	−.06	62.6	−.7	86	20	74	36	7	52	34	53	46	61	6.01	+1.2	11	8.2	s.	38	se.	23	14	7	9	4.0	.0	.0
Mobile	57	86	105	29.92	29.98	−.04	67.0	+.7	86	16	76	44	1	58	28	60	57	77	7.49	+2.9	9	10.4	s.	50	e.	30	13	9	8	4.5	.0	.0
Montgomery	218	92	105	29.74	29.99	−.04	64.7	−.6	87	19	76	40	7	54	31	56	50	66	6.62	+2.3	9	7.5	sw.	31	w.	5	15	6	9	4.3	.0	.0
Meridian	375	67	92	29.56	29.95	−.07	64.8	+.8	90	29	77	37	1	53	35	56	49	64	2.72	−2.1	7	7.0	sw.	29	se.	30	15	8	7	3.8	.0	.0
Vicksburg	247	65	73	29.70	29.96	−.04	66.0	+.4	87	17	76	43	6	56	30	57	51	66	3.48	−1.7	10	8.1	s.	35	s.	4	12	6	12	5.2	.0	.0
New Orleans	53	76	84	29.93	29.98	−.02	69.2	+.4	85	16	78	45	1	60	24	62	57	73	7.42	+2.2	8	7.3	se.	28	se.	4	11	10	9	4.8	.0	.0
West Gulf States							66.4	0.0										68	1.30	−2.4										4.8		
Shreveport	249	92	227	29.66	29.93	−.04	66.6	+.8	87	16	77	41	6	56	28	58	53	67	2.43	−2.2	7	12.2	s.	40	se.	13	13	9	8	4.6	.0	.0
Bentonville	1,303	12	38	28.53	29.90	−.06	57.6	+.7	87	17	68	29	6	48	35	...	...	...	3.64	−.7	10	8.9	s.	24	s.	7	8	12	10	.....	1.3	.0
Fort Smith	457	79	94	29.41	29.89	−.07	61.6	−.2	89	17	72	34	6	52	34	53	46	61	2.88	−1.1	7	9.9	s.	37	w.	25	11	13	6	5.0	T	.0
Little Rock	357	94	102	29.55	29.92	−.06	62.0	−.1	90	17	72	34	6	52	30	53	46	61	1.90	−3.3	8	9.5	s.	33	w.	25	9	10	11	5.4	.0	.0
Austin	605	136	148	29.27	29.90	.....	68.6	+.8	95	29	80	37	6	58	37	59	51	62	.63	−3.7	2	9.6	s.	30	s.	20	11	13	6	4.5	.0	.0
Brownsville	57	88	96	29.82	29.88	.....	72.4	−1.3	99	29	80	49	6	65	28	66	63	79	.51	−.9	4	12.1	se.	29	s.	23	9	15	6	4.8	.0	.0
Corpus Christi	20	11	78	29.88	29.90	−.05	70.6	−.2	87	4	77	48	5	64	25	65	62	80	.43	−1.4	2	12.5	se.	32	n.	24	7	16	7	5.5	.0	.0
Dallas	512	220	227	29.35	29.89	.....	65.6	.....	91	28	76	39	5	55	31	56	48	60	.64	−3.6	3	14.1	se.	43	w.	7	12	8	10	4.6	.0	.0
Fort Worth	679	92	110	29.20	29.90	−.04	66.2	+1.2	92	28	78	39	6	55	34	...	...	...	.58	−3.4	2	12.8	s.	38	n.	8	17	6	7	3.4	.0	.0
Galveston	54	106	114	29.89	29.95	−.02	67.3	−1.4	82	21	72	48	5	63	20	63	61	85	1.07	−2.0	5	11.9	s.	29	nw.	8	12	14	4	4.3	.0	.0
Houston	138	292	314	29.80	29.95	.....	68.4	−.9	87	29	78	45	6	59	27	...	...	...	.33	−3.2	6	13.2	se.	28	nw.	8	9	11	10	5.6	.0	.0
Palestine	510	64	72	29.41	29.94	−.02	65.9	−.1	89	29	76	38	6	56	32	58	53	68	1.40	−3.0	7	9.2	s.	25	nw.	20	11	11	8	5.0	.0	.0
Port Arthur	34	98	106	29.92	29.96	.....	67.0	.....	83	21	73	45	9	60	24	...	...	...	.86	−2.1	5	11.7	s.	30	nw.	8	11	13	6	5.1	.0	.0
San Antonio	693	242	301	29.18	29.89	−.04	70.0	+.9	90	28	82	42	5	58	38	59	50	59	.84	−2.4	3	12.4	se.	42	w.	20	12	14	4	4.7	.0	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, April 1937*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min.÷2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch, or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Ohio Valley and Tennessee	*Ft.*	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	*°F.*	*°F.*	*°F.*		*°F.*	*°F.*		*°F.*	*°F.*	*°F.*	*°F.*	*%*	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
							54.4	−0.4										65	4.18	+0.5										6.5		
Chattanooga	762	71	214	29.16	29.97	−0.06	60.1	−.2	88	18	71	37	12	50	38	51	43	59	6.19	+1.3	10	8.4	w.	32	sw.	21	15	3	12	5.1	.0	.0
Knoxville	995	66	84	28.91	29.96	−.07	58.4	+.4	88	18	69	33	12	48	38	50	43	63	3.04	−1.1	11	6.8	w.	25	sw.	21	14	5	11	5.0	.0	.0
Memphis	399	78	86	29.49	29.92	−.08	62.6	+.8	90	17	72	40	10	54	28	53	45	58	3.59	−1.2	9	9.2	sw.	27	sw.	24	7	12	11	6.1	.0	.0
Nashville	546	168	188	29.38	29.97	−.04	59.0	.0	87	18	70	36	12	48	38	50	44	62	3.73	−.4	10	10.6	se.	56	nw.	5	5	14	11	5.9	.0	.0
Lexington	989	6	----	----	----	----	54.0	−.3	86	23	66	28	10	42	40	----	----	----	5.32	+1.8	14	----	s.	----	----	----	14	16	10	----	0	.0
Louisville	525	188	234	29.37	29.96	−.05	55.3	−1.1	84	23	65	35	10	46	38	49	44	70	4.06	+.2	12	11.3	sw.	35	s.	21	7	10	13	6.2	.0	.0
Evansville	431	76	116	29.46	29.93	−.07	56.0	−.7	85	23	65	35	11	47	32	48	42	64	4.24	+.3	16	10.5	s.	38	sw.	24	4	10	16	6.6	.0	.0
Indianapolis	822	194	230	29.04	29.94	−.06	50.7	−1.4	83	17	60	30	10	42	37	44	38	67	4.27	+.6	14	12.5	w.	31	w.	21	3	7	20	7.6	T	.0
Terre Haute	575	63	149	29.28	29.90	----	52.8	----	86	17	62	34	9	43	36	46	40	69	5.57	+1.9	14	11.0	se.	33	sw.	14	7	5	18	6.9	T	.0
Cincinnati	627	11	51	29.26	29.94	−.07	52.7	+.3	83	23	63	29	11	42	38	46	40	68	2.93	−.2	15	9.0	sw.	30	sw.	1	5	7	18	7.1	.0	.0
Columbus	822	90	210	29.07	29.95	−.07	51.1	−.1	82	23	61	31	11	42	39	44	38	66	3.16	+.3	15	11.3	s.	37	s.	21	5	14	11	6.4	T	.0
Dayton	900	58	153	28.98	29.94	----	51.4	−.2	82	23	61	30	11	42	36	----	----	----	4.78	+1.6	14	10.0	sw.	31	w.	5	4	12	14	6.9	T	.0
Elkins	1,947	59	78	27.93	30.00	−.03	48.6	−.2	81	21	60	23	1	38	51	42	36	68	4.65	+1.0	16	8.3	nw.	34	w.	15	6	8	16	7.0	T	.0
Parkersburg	637	77	84	29.33	29.99	−.04	53.4	.0	85	23	64	29	1	43	44	45	39	65	2.19	−1.0	15	7.9	se.	26	nw.	18	4	6	20	7.0	.1	.0
Pittsburgh [1]	1,273	39	54	28.58	29.95	−.07	47.8	−3.4	76	18	57	29	12	39	33	41	35	69	5.62	+2.7	17	13.3	nw.	33	w.	2	4	5	21	7.5	T	.0
							45.1	−0.2										71	4.25	+1.7										7.0		
Lower Lake Region																																
Buffalo	768	243	280	29.13	29.97	−.04	43.0	+.2	67	30	50	28	10	36	28	39	35	79	4.58	+2.0	17	15.7	sw.	54	sw.	6	6	7	17	7.1	.5	.0
Canton	448	10	61	29.51	30.00	----	42.5	.0	69	25	52	21	1	33	32	38	32	72	3.70	+1.5	13	9.7	e.	35	sw.	6	5	9	16	6.9	1.0	.0
Ithaca	836	77	100	29.07	29.99	----	43.8	−1.2	72	30	53	27	17	35	32	39	32	68	3.75	+1.2	17	11.3	nw.	44	se.	5	4	8	18	7.5	3.6	.0
Oswego	335	71	85	29.62	29.99	−.02	43.3	−.3	65	24	50	29	3	36	28	38	33	70	2.37	.0	14	10.8	se.	28	se.	22	7	6	17	6.7	3.6	.0
Rochester	523	86	102	29.42	30.00	−.01	44.8	−.1	66	13	52	29	10	37	26	39	33	67	3.42	+1.1	20	9.3	w.	34	sw.	6	6	7	17	6.8	1.0	.0
Syracuse	596	65	79	29.34	29.99	−.02	45.5	+.8	70	30	53	29	3	38	26	----	----	----	3.51	+1.0	16	8.2	e.	22	se.	5	3	11	16	7.1	6.4	.0
Erie	714	130	166	29.18	29.96	−.06	45.2	+.1	70	30	53	30	9	38	31	39	34	71	7.03	+4.3	16	14.9	w.	43	se.	24	6	9	15	6.8	T	.0
Cleveland	762	267	318	29.11	29.94	−.08	47.1	+.9	71	17	55	30	9	39	31	42	36	70	3.33	+.9	14	16.4	se.	43	sw.	6	5	10	15	6.8	.1	.0
Sandusky	629	5	67	29.26	29.94	−.08	47.1	−.1	74	4	56	31	7	38	38	----	----	----	4.41	+1.9	14	10.6	e.	30	sw.	13	6	9	15	6.9	T	.0
Toledo	628	79	87	29.26	29.95	−.06	46.4	−1.2	76	17	54	30	11	38	37	42	37	72	4.77	+2.1	13	11.0	e.	32	w.	13	7	10	13	6.5	T	.0
Fort Wayne	857	69	84	29.00	29.94	----	48.1	−.3	80	23	57	28	11	39	41	42	38	73	5.06	+2.0	17	10.6	nw.	31	w.	13	3	14	13	6.9	.5	.0
Detroit [1]	626	5	78	29.26	29.95	−.07	44.8	−1.4	68	4	53	26	3	36	32	40	35	72	5.03	+2.6	17	11.6	e.	38	sw.	13	4	9	17	7.5	T	.0
							41.4	−0.2										76	3.59	+1.1										7.2		
Upper Lake Region																																
Alpena	609	13	89	29.29	29.97	−.05	39.1	+.5	58	19	45	23	3	33	28	36	32	79	3.15	+.9	15	13.2	nw.	43	e.	21	6	7	17	7.1	.5	.0
Escanaba	612	41	49	29.30	29.98	−.04	38.9	+1.0	66	18	46	19	3	32	36	35	30	75	2.31	+.1	10	9.5	n.	25	ne.	21	7	6	17	7.0	8.5	.0
Grand Rapids	707	70	244	29.16	29.94	−.08	45.8	−1.2	72	4	54	28	3	37	36	40	35	72	4.78	+2.0	15	12.6	se.	43	w.	13	5	8	17	7.4	.9	.0
Lansing	878	5	90	28.98	29.93	----	44.2	−1.4	69	4	53	25	16	35	34	40	36	79	6.33	+3.8	15	10.3	e.	32	s.	13	6	4	20	7.4	8.0	.0
Ludington	637	5	54	29.22	29.93	----	42.8	+.9	73	30	50	23	3	35	34	38	----	----	2.53	.0	10	----	e.	----	----	----	6	8	14	----	2	.0
Marquette	734	44	69	29.16	29.98	−.04	37.8	.0	66	30	44	24	16	32	26	35	32	82	2.04	−.4	13	9.4	nw.	32	se.	24	6	9	15	6.8	13.9	.0
Sault Sainte Marie	614	11	52	29.29	30.00	−.03	38.6	+1.2	68	29	45	20	3	32	30	35	30	74	2.32	+.1	13	10.2	se.	30	se.	13	6	5	19	7.3	.3	.0
Chicago	673	7	131	29.19	29.92	−.08	46.5	−.4	80	23	54	31	2	39	39	41	36	73	4.61	+1.8	15	11.2	e.	27	w.	13	6	5	20	7.7	.2	.0
Green Bay	617	109	141	29.25	29.91	−.10	41.8	−1.4	67	18	49	25	3	35	27	37	32	72	3.42	+.8	14	12.2	ne.	40	n.	21	5	5	20	7.7	T	.0
Milwaukee	681	97	221	29.17	29.92	−.07	42.7	−1.1	70	19	49	29	10	37	27	38	34	74	4.80	+2.1	15	13.6	n.	38	e.	21	5	7	18	7.4	T	.0
Duluth	1,133	5	47	28.70	29.94	−.07	37.0	.0	64	18	43	20	2	31	26	34	30	79	3.17	+1.1	14	13.5	ne.	37	nw.	13	6	6	18	7.1	5.4	.0
							40.9	−0.1										73	2.58	+1.0										6.6		
North Dakota																																
Moorhead, Minn	940	50	58	28.90	29.93	−.06	40.8	+.2	62	17	49	21	1	33	30	37	33	79	4.69	+2.5	10	10.5	n.	31	n.	24	2	11	17	7.6	16.7	.0
Bismarck	1,674	8	57	28.12	29.92	−.05	42.8	+.7	73	21	53	15	4	33	38	37	31	68	1.43	−.1	5	11.7	nw.	35	nw.	12	6	12	12	6.4	12.4	.0
Devils Lake	1,478	11	44	28.35	29.95	−.04	38.3	−.5	63	11	47	15	4	29	31	35	31	81	1.23	−.3	13	11.2	e.	38	nw.	24	6	6	18	7.2	2.8	.0
Grand Forks	833	12	67	----	----	----	39.6	−2.1	63	11	48	17	1	32	33	36	----	----	4.62	+3.0	13	----	se.	38	nw.	24	3	10	17	----	9.6	.0
Williston	1,878	42	50	27.93	29.93	−.03	43.2	+1.2	77	15	54	10	4	33	33	36	29	63	.93	−.3	8	9.6	se.	30	w.	15	11	9	10	5.2	5.5	.0
							49.3	−1.0										72	3.80	+0.8										7.1		
Upper Mississippi Valley																																
Minneapolis	919	105	208	28.90	29.90	----	44.5	−1.9	67	23	52	25	2	37	27	39	33	67	2.62	+.4	13	12.2	e.	33	e.	24	6	4	20	7.3	3.6	.0
La Crosse	714	11	48	29.11	29.89	−.09	46.2	−1.0	76	23	55	26	2	38	34	41	37	76	3.15	+.7	16	6.8	nw.	20	w.	18	6	5	19	7.2	.2	.0
Madison	974	70	78	28.84	29.90	−.09	43.4	−2.0	70	19	50	27	2	36	26	39	34	74	3.54	+.8	16	9.5	se.	32	n.	15	6	3	21	7.7	T	.0
Charles City	1,015	10	51	28.79	29.89	−.09	45.8	−.6	77	23	54	28	11	38	35	41	36	75	3.44	+.9	16	7.9	se.	21	sw.	24	7	5	18	6.7	1.7	.0
Davenport	606	66	161	29.22	29.88	−.10	49.2	−.7	81	23	57	31	2	41	34	44	39	72	3.86	+1.2	17	11.2	se.	35	sw.	24	5	6	19	7.4	.2	.0
Des Moines	861	5	99	28.96	29.87	−.10	49.0	−1.1	80	23	58	28	6	40	39	44	39	72	3.29	+.4	16	7.5	se.	24	se.	24	8	3	19	7.4	.2	.0
Dubuque	699	60	79	29.13	29.88	−.10	47.2	−1.4	81	23	55	30	2	40	38	42	37	71	3.29	+.4	16	9.6	se.	35	sw.	24	5	7	18	7.5	.6	.0
Keokuk	614	64	78	29.22	29.88	−.10	51.1	−1.2	82	23	60	31	6	43	32	45	39	70	3.89	+.9	14	10.7	s.	30	sw.	14	6	9	15	6.3	.0	.0
Cairo	358	87	93	29.53	29.91	−.08	58.4	+.3	88	17	67	38	2	50	30	51	45	68	4.39	+.7	11	8.4	se.	23	ne.	3	7	6	17	6.7	T	.0
Peoria	609	11	45	29.23	29.90	−.09	49.7	−1.2	81	17	59	28	11	41	32	45	41	76	4.42	+1.0	16	12.9	se.	35	sw.	24	3	5	22	7.7	T	.0
Springfield, Ill	636	5	191	29.21	29.88	−.10	52.6	−.1	89	17	62	34	9	43	35	46	42	72	3.64	+.1	15	13.5	s.	45	sw.	24	5	13	12	6.3	.0	.0
St. Louis	568	179	303	29.28	29.89	−.09	55.0	−1.1	89	17	64	35	5	46	34	48	42	68	6.03	+2.2	16									6.5		
							50.5	−0.8										67	2.45	−0.4												
Missouri Valley																																
Columbia, Mo	784	6	64	29.03	29.87	−.11	53.9	−1.0	86	22	64	28	6	44	36	----	----	----	3.75	.0	13	9.9	nw.	32	se.	29	6	9	15	6.8	T	.0
Kansas City [1]	750	32	45	29.06	29.87	−.09	54.0	−.8	82	22	64	29	6	44	37	47	41	66	2.51	−.6	9	12.4	nw.	41	w.	24	5	9	16	7.1	T	.0
St. Joseph	967	11	49	28.83	29.87	----	52.9	----	82	22	62	31	5	43	32	46	40	67	2.01	−1.2	9	11.7	nw.	43	nw.	24	10	7	13	6.1	T	.0
Springfield, Mo	1,324	98	104	28.48	29.88	−.09	55.0	−1.0	87	17	64	30	6	46	36	48	43	68	5.19	+1.3	12	12.3	se.	31	s.	29	7	13	10	5.6	T	.0
Topeka	987	65	87	28.81	29.86	----	54.4	−.3	85	22	65	30	5	44	37	47	40	64	1.76	−1.0	7	11.5	nw.	30	nw.	24	4	13	13	6.4	2.0	.0
Lincoln	1,189	11	81	28.60	29.87	−.07	51.1	−.4	87	22	61	27	5	41	35	44	36	63	1.22	−1.3	8	13.0	n.	48	nw.	24	4	11	15	6.6	T	.0
Omaha [1]	982	31	44	28.81	29.87	−.08	49.9	−1.3	85	22	59	30	5	41	36	43	37	68	1.67	−.8	10	14.4	nw.	54	nw.	24	10	4	16	6.7	.2	.0
Valentine	2,598	47	54	27.19	29.92	−.02	45.3	−.4	79	21	57	22	5	34	46	37	29	61	1.22	−.6	7	11.4	nw.	32	nw.	12	5	11	14	6.5	2.8	.0
Sioux City	1,138	64	106	28.65	29.87	−.08	47.2	−.6	81	22	56	27	5	38	39	41	36	71	2.77	+.1	10	12.3	nw.	45	nw.	24	4	11	15	7.0	8.8	.0
Huron	1,307	59	74	28.49	29.91	−.05	48.6	−1.5	74	19	52	11	5	35	34	38	33	72	2.43	+.2	12	11.7	nw.	46	nw.	24	6	10	14	6.5	12.0	.0
							43.4	0.0										57	1.12	−0.4										6.5		
Northern Slope																																
Havre	2,507	11	67	27.22	29.86	−.07	47.2	+3.5	78	26	59	25	4	35	38	37	25	48	.31	−.7	6	11.3	sw.	38	w.	13	8	16	6	5.1	3.1	.0
Helena	4,124	85	111	25.72	29.91	−.06	43.6	+.1	75	26	54	22	24	33	38	35	26	52	.57	−.6	7	10.8	sw.	30	w.	15	2	10	18	7.7	1.8	.0
Missoula	3,263	80	91	----	----	----	44.4	−.8	82	26	54	27	8	34	42	----	----	----	.93	−.1	16	7.3	w.	30	nw.	9	2	0	28	8.4	.4	.0
Kalispell	2,973	48	56	26.86	29.93	−.03	42.4	−1.2	76	26	52	25	12	33	37	36	30	66	1.22	+.4	11	7.1	se.	27	sw.	13	1	2	27	8.2	T	.0
Miles City	2,371	48	55	27.38	29.94	−.02	46.6	+1.6	81	15	57	26	3	36	35	37	26	52	.79	−.3	6	8.2	w.	31	nw.	15	10	8	12	5.7	.8	.0
Rapid City	3,259	50	58	26.52	29.96	+.01	44.1	−.2	83	15	54	20	4	34	38	37	28	59	.50	−1.5	6	10.1	n.	33	n.	24	10	12	8	5.3	.4	.0
Cheyenne [1]	6,144	5	39	23.84	29.88	−.03	41.0	+.1	74	15	54	17	9	28	40	33	24	55	1.59	−.4	9	14.7	nw.	49	nw.	14	5	16	9	6.2	15.1	.0
Lander	5,372	60	68	24.54	29.91	−.03	41.4	−1.0	72	15	54	21	8	29	39	33	24	55	2.58	+.5	11	6.5	sw.	32	sw.	15	5	17	8	6.0	16.7	.0
Sheridan	3,790	10	47	25.99	29.91	----	44.0	----	82	15	56	23	4	32	41	36	29	64	1.24	−.7	12	7.6	nw.	30	se.	27	7	13	10	5.6	.6	.0
Yellowstone Park	6,241	12	46	23.78	29.99	+.03	35.2	−1.4	66	26	46	9	3	25	38	29	22	62	1.54	+.4	16	8.7	sw.	32	sw.	21	5	5	20	7.3	13.7	.0
North Platte	2,821	11	51	26.95	29.88	−.04	48.4	−.2	82	21	61	24	5	36	46	39	30	56	1.09	−1.0	4	9.9	n.	31	n.	24	6	10	14	6.1	4.0	.0

[1] Observations taken at airport.

TABLE 2.—*Climatological data for Weather Bureau stations, April 1937*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01 inch, or more	Wind: Average hourly velocity	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	°*F.*	°*F.*	°*F.*		°*F.*	°*F.*		°*F.*	°*F.*	°*F.*	°*F.*	%	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
Middle Slope							**53.8**	**+0.4**										**53**	**1.08**	**−1.2**										**5.0**		
Denver	5,292	106	113	24.61	29.86	−0.04	47.3	+0.2	82	15	59	26	8	35	41	37	24	48	1.43	−0.6	8	8.7	s.	32	nw.	7	8	11	11	5.7	12.8	0.0
Pueblo	4,685	80	86	25.17	29.83	−.05	51.4	+1.3	85	15	66	28	25	37	43	39	24	44	.84	−.5	6	8.1	nw.	32	w.	6	11	12	7	4.8	2.8	.0
Concordia	1,392	50	58	28.40	29.88	−.05	52.8	−.7	89	22	63	24	5	42	34	44	35	58	.46	−1.9	4	11.0	n.	36	nw.	24	6	14	10	5.8	.0	.0
Dodge City	2,509	10	86	27.29	29.88	−.02	54.6	+1.0	91	22	68	23	5	41	39	43	31	50	.52	−1.4	2	14.6	n.	35	s.	11	12	13	5	4.7	.0	.0
Wichita	1,358	85	93	28.44	29.86	−.07	56.0	−.4	87	16	66	26	5	46	35	47	39	57	.57	−2.3	3	13.0	n.	34	s.	22	14	6	10	4.8	.0	.0
Oklahoma City	1,214	10	47	28.59	29.86	−.06	60.6	+.8	91	16	72	30	5	49	39	51	43	60	2.66	−.6	5	11.9	s.	30	nw.	7	15	6	9	4.5	.0	.0
Southern Slope							**64.2**	**+1.3**										**42**	**0.74**	**−1.0**										**3.8**		
Abilene	1,738	10	52	28.07	29.85	−.05	66.4	+2.0	95	16	80	32	5	53	37	52	40	47	1.16	−1.6	2	12.3	s.	30	w.	7	15	6	9	4.2	.0	.0
Amarillo	3,676	10	49	26.16	29.84	−.03	57.5	+1.7	94	16	71	30	8	44	41	44	28	42	.39	−1.4	3	11.0	sw.	32	nw.	7	15	10	5	4.0	1.1	.0
Del Rio	960	63	71	28.85	29.82	−.07	71.9	+1.3	99	23	85	43	5	59	36	58	46	49	.18	−1.6	1	11.4	se.	37	nw.	4	16	9	5	3.9	.0	.0
Roswell	3,566	75	85	26.25	29.81	−.04	60.8	+.2	93	16	76	28	5	45	43	44	22	30	1.25	+.4	2	10.0	s.	43	nw.	7	20	8	2	2.9	T	.0
Southern Plateau							**47.5**	**+0.6**										**34**	**0.15**	**−0.4**										**2.5**		
El Paso	3,778	82	101	26.10	29.82	−.01	64.4	+1.0	93	16	79	37	5	50	39	46	24	24	T	−.3	0	9.2	w.	30	nw.	3	24	4	2	1.8	.0	.0
Albuquerque [1]	4,972	5	39	24.95	29.81	------	54.0	.0	86	15	71	29	5	37	45	39	21	35	.42	−.2	3	10.6	w.	42	nw.	23	19	7	4	3.3	1.5	.0
Santa Fe	7,013	38	53	23.14	29.82	−.02	47.9	+1.2	77	15	61	24	5	35	36	36	20	37	.49	−.5	3	7.6	sw.	27	sw.	27	17	4	9	4.1	3.5	.0
Flagstaff	6,907	10	59	23.32	29.82	−.02	43.2	+1.0	75	14	59	19	29	28	44	34	----	49	.16	−1.1	2	9.8	sw.	28	sw.	27	12	15	3	----	T	.0
Phoenix	1,107	39	51	28.71	29.85	−.02	67.6	+.6	96	15	83	44	5	52	42	49	30	29	T	−.4	0	6.8	e.	27	w.	22	24	2	4	2.1	.0	.0
Yuma	141	9	54	29.73	29.88	−.01	70.2	+.7	101	15	86	49	29	54	44	52	32	30	.00	−.1	0	6.9	w.	28	w.	27	27	2	1	1.1	.0	.0
Independence	3,957	5	26	25.92	29.94	+.04	54.9	−.2	83	15	71	30	23	39	41	40	20	----	T	−.1	0	-------	s.	----	------	---	25	3	2	----	.0	.0
Middle Plateau							**46.5**	**−1.9**										**47**	**0.56**	**−0.3**										**5.1**		
Reno	4,527	61	76	25.45	30.00	+.03	46.4	−1.1	74	20	59	23	7	34	38	37	25	47	.21	−.3	4	8.6	w.	30	w.	21	15	7	8	4.1	.1	0
Tonopah	6,090	12	20	----	----	----	45.1	------	72	14	56	24	28	35	29	34	21	46	.58	------	2	----	nw.	----	------	---	----	----	----	----	----	----
Winnemucca	4,344	18	56	25.58	29.99	+.03	44.4	−2.3	75	26	59	20	17	30	45	36	25	52	1.29	+.4	7	8.9	sw.	30	nw.	21	11	9	10	5.1	2.1	.0
Modena	5,473	10	43	24.54	29.88	.00	44.6	−1.4	76	14	60	20	18	29	45	35	22	46	.29	−.6	4	11.6	sw.	37	sw.	27	11	8	11	5.1	.7	.0
Salt Lake City [1]	4,227	32	46	25.67	29.93	+.01	46.4	−3.2	78	15	59	28	24	34	42	38	28	53	1.09	------	10	10.1	se.	38	s.	27	9	8	13	6.1	2.2	.0
Grand Junction	4,602	60	68	25.28	29.84	−.04	50.8	−1.6	84	15	64	30	18	37	39	39	24	37	.22	−.6	2	7.8	se.	32	sw.	27	9	12	9	5.1	T	.0
Northern Plateau							**47.1**	**−2.2**										**57**	**1.86**	**+0.7**										**6.9**		
Baker	3,471	48	53	26.42	30.02	+.02	43.2	−2.0	72	26	54	25	17	33	36	37	28	59	.70	−.4	12	7.2	se.	23	s.	13	4	7	19	7.5	2.1	.0
Boise	2,739	79	87	27.14	30.01	+.03	48.2	−2.2	81	26	59	28	17	38	33	40	30	53	1.50	+.3	11	8.1	se.	24	nw.	21	4	13	13	6.5	.6	.0
Pocatello	4,447	60	68	25.41	29.95	+.01	43.3	−2.7	73	26	53	23	24	34	34	36	28	59	1.89	+.5	14	11.1	sw.	32	sw.	2	7	7	16	6.5	7.2	.0
Spokane	1,929	101	110	27.90	29.96	−.03	46.6	−1.8	72	25	55	33	2	38	30	40	32	62	2.53	+1.4	17	8.8	s.	28	s.	13	2	14	14	7.5	T	.0
Walla Walla	991	57	65	28.92	30.00	−.01	51.2	−1.9	77	25	60	36	21	42	29	43	35	58	3.09	+1.6	15	7.6	s.	28	w.	13	4	9	17	6.9	T	.0
Yakima	1,076	58	67	28.82	29.97	------	50.2	−2.3	73	30	60	32	11	40	34	41	30	50	1.46	+1.0	6	7.4	nw.	29	nw.	4	3	16	11	6.4	T	.0
North Pacific Coast Region							**48.4**	**−1.2**										**75**	**5.91**	**+2.8**										**8.5**		
North Head	211	11	56	29.83	30.06	+.01	46.2	−1.3	62	7	50	39	20	42	20	44	42	85	7.16	+3.0	26	18.4	s.	61	s.	9	0	3	27	9.0	.0	.0
Seattle	125	90	321	29.88	30.01	−.02	49.2	−.2	66	7	56	38	21	43	27	44	39	71	4.56	+2.2	18	11.3	se.	49	sw.	14	0	13	17	7.8	.0	.0
Tatoosh Island	86	10	54	29.88	29.98	−.02	45.7	−.4	55	8	49	38	4	42	13	43	41	83	10.79	+5.2	27	16.2	s.	51	s.	13	0	3	27	9.0	.0	.0
Medford [1]	1,329	29	58	28.65	30.07	------	49.4	−2.7	77	24	61	30	11	38	43	43	36	68	2.56	+1.3	13	-------	nw.	----	------	---	4	12	14	----	T	.0
Portland, Oreg	153	68	106	29.90	30.05	−.01	50.0	−1.8	67	30	57	38	21	43	26	45	40	73	6.22	+3.4	20	7.1	se.	21	sw.	5	1	2	27	8.9	.0	.0
Roseburg	510	45	76	29.54	30.10	+.03	49.9	−1.1	75	29	60	33	29	39	38	44	39	71	4.14	+1.9	19	5.1	n.	21	w.	5	3	3	24	8.0	.0	.0
Middle Pacific Coast Region							**54.4**	**−1.3**										**65**	**2.80**	**+0.5**										**4.7**		
Eureka	62	73	89	30.09	30.16	+.05	49.5	−.4	66	14	55	38	11	44	19	46	42	76	6.55	+3.2	17	9.4	n.	31	n.	21	9	6	15	5.9	.0	.0
Redding [1]	722	20	34	----	----	----	55.9	−3.9	84	20	66	37	6	46	30	46	35	51	2.70	+.1	9	8.8	nw.	26	nw.	15	9	11	10	5.5	.0	.0
Sacramento	66	92	115	29.98	30.05	+.04	57.8	−.3	82	20	69	41	7	47	32	49	40	59	1.10	−.4	5	8.1	s.	27	nw.	16	18	5	7	3.4	.0	.0
San Francisco	155	112	132	29.91	30.08	+.03	54.5	−.5	73	20	60	46	2	49	23	49	45	74	.86	−.8	6	9.2	w.	25	w.	3	15	7	8	3.9	.0	.0
South Pacific Coast Region							**60.7**	**+1.4**										**62**	**0.23**	**−0.7**										**3.7**		
Fresno	327	97	105	29.69	30.04	+.05	60.2	.0	85	25	73	43	11	48	34	51	41	56	.33	−.9	5	6.8	nw.	31	nw.	26	14	12	4	3.7	.0	.0
Los Angeles	338	159	191	29.62	29.99	.00	62.3	+2.9	86	24	72	48	27	53	30	52	44	60	.24	−.8	2	6.2	sw.	23	nw.	3	17	9	4	3.1	.0	.0
San Diego	87	62	70	29.89	29.98	−.01	59.7	+1.2	76	24	67	50	4	53	24	53	49	71	.13	−.6	4	7.0	w.	22	w.	2	14	8	8	4.3	.0	.0
West Indies																																
San Juan, P. R	82	9	54	29.91	29.99	------	77.4	+.8	88	11	82	70	12	73	15	----	----	----	1.34	−3.0	13	11.8	e.	28	e.	13	6	21	3	4.5	.0	.0
Panama Canal																																
Balboa Heights	118	6	92	------	[3] 29.83	.00	82.0	+.4	94	28	90	71	1	74	20	----	----	[3] 77	1.32	−1.6	7	8.3	nw.	22	n.	10	4	25	1	5.0	.0	.0
Cristobal	36	6	97	------	[3] 29.86	.00	82.9	+1.1	92	25	87	76	10	79	14	76	74	[3] 74	1.65	−2.5	14	11.9	n.	25	n.	13	12	13	5	4.7	.0	.0
Alaska																																
Fairbanks	454	11	87	[3] 29.27	[3] 29.80	------	23.8	−4.9	45	16	35	−11	1	12	45	22	15	65	.42	+.1	9	5.9	s.	21	sw.	25	5	10	15	6.7	7.9	28.5
Juneau	80	96	116	[3] 29.64	[3] 29.73	------	40.6	+.2	54	13	46	32	25	35	21	37	30	68	5.79	+.5	24	8.4	s.	36	ne.	24	3	3	24	8.4	7.2	.0
Nome	22	5	32	[3] 29.84	[3] 29.86	------	16.3	−.9	35	24	25	−12	10	8	30	16	10	70	1.06	+.5	9	8.3	n.	42	n.	26	9	8	13	6.0	7.1	29.1
Hawaiian Islands																																
Honolulu	38	86	100	[3] 30.01	[3] 30.05	------	73.7	+.7	81	15	78	68	19	70	12	66	62	70	2.30	+.2	12	9.8	e.	22	ne.	4	7	14	9	5.6	.0	.0

[1] Observations taken at airport.
[2] Observations taken hourly.
[3] Pressure not reduced to mean of 24 hours.

TABLE 3.—*Data furnished by the Canadian Meteorological Service, April 1937*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max.+ mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	*In.*	*In.*	*In.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*In.*	*In.*	*In.*
Cape Race, Newfoundland	99												
Sydney, Cape Breton Island	48	29.91	29.96	+0.07	37.1	+2.1	44.3	30.0	69	20	2.37	−1.48	7.1
Halifax, Nova Scotia	88	29.75	29.86	−.10	38.8	+1.0	45.7	31.9	66	21	2.30	−1.88	4.6
Yarmouth, Nova Scotia	65	29.88	29.95	−.01	41.1	+2.2	48.4	33.8	68	24	4.80	+.98	4.4
Charlottetown, Prince Edward Island	38	29.92	29.96	+.06	37.5	+2.3	44.4	30.7	67	22	1.49	−1.16	4.5
Chatham, New Brunswick	28												
Father Point, Quebec	20	29.98	30.00	+.07	36.7	+3.5	42.8	30.6	58	20	.72	−.86	.3
Quebec, Quebec	296	29.66	29.99	.00	40.5	+5.4	47.4	33.6	67	20	2.04	−.05	.4
Doucet, Quebec	1,236				33.5		46.8	20.2	71	−15	1.61		3.5
Montreal, Quebec	187												
Ottawa, Ontario	236	29.74	30.01	−.01	40.9	+.9	49.8	32.0	68	19	2.63	+1.13	3.1
Kingston, Ontario	285	29.68	30.00	−.02	42.6	+2.6	50.0	35.3	68	27	3.40	+1.61	.1
Toronto, Ontario	379	29.56	29.98	−.04	43.2	+2.4	49.7	36.8	65	29	4.02	+1.65	.1
Cochrane, Ontario	930				35.5		44.4	26.7	75	5	2.45		19.6
White River, Ontario	1,244	28.65	29.99	−.05	35.4	+2.4	46.5	24.4	74	−2	2.35	+1.10	14.3
London, Ontario	808				41.6		49.1	34.1	66	25	8.47		2.0
Southampton, Ontario	656	29.24	29.97	−.06	39.6	+.9	46.5	32.8	70	24	4.21	+2.41	2.0
Parry Sound, Ontario	688	29.26	29.96	−.06	40.6	+3.0	47.7	33.4	74	22	4.21	+2.30	3.2
Port Arthur, Ontario	644	29.34	30.06	+.03	35.4	+1.9	43.7	27.1	58	12	2.79	+1.07	10.9
Winnipeg, Manitoba	760	29.13	29.97	−.05	37.8	+1.9	45.7	30.0	61	13	2.64	+1.59	12.6
Minnedosa, Manitoba	1,690	28.13	29.98	−.03	36.4	+.4	45.2	27.6	63	5	1.93	+.87	6.9
Le Pas, Manitoba	860				36.0		46.6	25.4	65	3	1.87		3.2
Qu'Appelle, Saskatchewan	2,115	27.63	29.89	−.10	39.0	+1.6	51.3	26.8	65	3	.29	−.76	2.4
Moose Jaw, Saskatchewan	1,759				42.2		54.7	29.8	66	10	.32		3.2
Swift Current, Saskatchewan	2,392	27.30	29.83	−.13	43.8	+2.5	55.4	32.2	73	17	.19	−.74	1.9
Medicine Hat, Alberta	2,365	27.34	29.82	−.10	47.3	+2.8	58.5	36.1	80	27	.32	−.42	.6
Calgary, Alberta	3,540												
Banff, Alberta	4,521												
Prince Albert, Saskatchewan	1,450	28.36	29.95	−.03	39.7	+3.6	49.3	30.0	66	13	1.17	+.34	.8
Battleford, Saskatchewan	1,592	28.13	29.88	−.09	41.2	+4.0	52.7	29.7	76	8	.67	+.20	1.2
Edmonton, Alberta	2,150	27.51	29.79	−.10	43.5	+3.6	54.8	32.2	73	22	.70	−.18	.3
Kamloops, British Columbia	1,262	28.59	29.89	−.04	48.6	−.3	58.6	38.6	72	30	.82	+.43	.0
Victoria, British Columbia	230	29.73	29.98	−.03	47.5	+.7	52.7	42.3	63	37	2.34	−.03	.0
Barkerville, British Columbia	4,180												
Estevan Point, British Columbia	20												
Prince Rupert, British Columbia	170				43.5		50.6	36.4	56	32	6.11		T
St. George's, Bermuda	158		30.05	.00	65.0	+.3	70.3	59.6	78	51	5.85	+1.50	.0
LATE REPORTS FOR MARCH 1937													
Cape Race, Newfoundland	99				27.5		32.4	22.6	42	11	5.56		33.1
Edmonton, Alberta	2,150	27.78	30.13	+0.17	27.5	+3.3	36.4	18.6	60	−3	.38	−0.34	3.8

TABLE 4.—*Severe local storms, April 1937*

[Compiled by Mary O. Souder from reports by Weather Bureau officials]

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the United States Meteorological Yearbook]

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Iowa,[1] northern portion	3					Sleet and snow	Telephone and telegraph communication interrupted; transportation delayed; highways hazardous under a coating of ice.
New Orleans, La	3	P. m.			$30,000	Wind and rain	Damage to roofs, shade trees, automobiles, and other property in the residential section.
Rock, Nobles, Jackson, Martin, and Faribault Counties, Minn.	3				5,000	Sleet and snow	Wires down, branches of trees broken, and traffic delayed.
Bismarck, Jamestown, and Dickinson, N. Dak.	3					Snow	From 5 to 10 inches of snow fell.
South Dakota[2]	3			1		Rain, sleet, and snow	Snowfall of 8 inches recorded. Highway and rail traffic and electric service interrupted. Party of motorists going from Brookings to Watertown stranded 5 miles from its destination and forced to walk the distance.
Panama City, Fla., vicinity of	4		34	0	3,500	Tornado	Property damaged; 2 persons injured; path 440 yards long.
Oil City, La	4					Electrical and hail	Considerable damage to roofs; crop loss.
Center, Tex	4	5 p. m.	1 10		4,000	Wind and hail	Property damaged; loss to crops.
Louisiana, northern portion	4-5					do	A series of storms occurred, the most severe one in the Red River Valley, 50 miles south-southeast of Shreveport. At Lake End, Red Oaks, and Campti buildings were demolished and several persons injured.
Lowndes, Montgomery, Macon, Bullock, Pike, Russell, and Chambers Counties, Ala.	5			6	100,000	Windstorms	30 persons injured; property damaged.
Nashville, Tenn	5					Wind	2 chimneys blown down; windows broken; signs down; power and light service interrupted. Damage estimated at several thousands.
North Miami Beach, Fla	6	4:15-4:30 p. m.			3,000	Thundersquall and hail.	One person injured; damage to power lines and awnings.
Watertown, N. Y	6					Wind	High wind caused much damage to telephone lines, windows, and signs.
New York, northern portion	6					Rain and snow	Village streets, highways, and farm lands inundated. In Madrid, an ice jam caused about $9,000 damage to power dam. Much damage to buildings along the river front. At Canton a machine shop was damaged to the extent of $2,000. In several other small towns in St. Lawrence, Franklin, and Clinton Counties many families were driven from their homes by flood waters. Considerable damage to factories and other buildings.
Florida,[2] Everglades area	6-7					Rain and hail	Bean and tomato crops on 50,000 acres were 90 to 95 percent destroyed.
Brundidge, Ala	8			4	20,000	Tornado	25 persons injured; property damaged.
Miami, Fla	9	4:30 a. m.	1 17	0	10,000	do	Several small frame houses demolished and a dozen others damaged. Several persons injured, 3 severely.
Greeley, Colo., and vicinity	11	p. m.				Wind and dust	Large plate-glass windows shattered; a number of rural electric power and telephone lines disabled. In light soil areas, sand drifted into ditches and roads and small acreages of early planted sugar beets were blown out.
Minnesota, extreme southwestern portion.	12				30,000	Flood	Snow and heavy rains caused the Redwood and Rock Rivers to overflow. Many residences, barns, and outbuildings flooded. Highways under water and lowlands inundated.
Fremont, Nebr	12	p. m.	1,000		1,000	Hail	No details.
Lyon County, Kans	13	1 p. m.	1 1		1,000	Heavy hail	Chief damage to automobile tops and buildings. Path 3 miles long.
Montgomery County, Kans	13	5-6 p. m.	1 3		2,500	do	Damage to roofs, greenhouses, and automobile tops. Path 4 miles long.
Heyworth, Ill	14	6:10 p. m.	440	0	75,000	Tornado	Property damaged; 2 persons injured. Path 1 mile long.
Ottoville, Ohio,[2] vicinity of	14	11 p. m.				Wind and rain	Barns and small farm buildings blow down. Considerable damage to a tile mill.
Fort Wayne, Ind., and vicinity	14	P. m.			50,000	Thundersquall with hail.	Several garages and front porches damaged; barn and filling station wrecked; several persons injured.
Springfield, Mo., vicinity of	14	do		0	25,000	Tornado	6 persons injured; livestock killed; property damaged.
Ottawa, Ill	14			1	50,000	Hail	Property damaged.
Lanark, Ill	14				500	do	Do.
Birmingham, Ala	15					do	Awnings and automobile tops damaged; several persons stunned being struck by falling hail.
Lee Pope, Ga., vicinity of	15				5,000	do	Loss to peach crop.
Greenwood, S. C., and vicinity	15	P. m.			5,000	Wind	Roofs and chimneys damaged; tenant house and trees blown down.
Elkins, W. Va	18	6:15 p. m.				Tornadic winds	Roof blown off a warehouse.
Buffalo, N. Y	18				500	Thunderstorm	Church damaged.
Roswell, N. Mex	19	5 p. m.	1 1		2,500	Heavy hail	Property damaged; small crop loss.
Knoxville, Tenn	21					Wind and rain	Damage to carnival tents and riding devices; 3 men were injured. In another part of the city, a frame garage was moved 30 feet from its foundation and demolished.
Montgomery County, Kans	23	5:30 p. m.	100	0	750	Tornado	Property damaged; 1 person injured; path 3 miles long.
Osage County, Kans	23	5:55 p. m.	300	0	10,900	do	Damage mostly to barns and smaller farm buildings; path 9 miles long
Bourbon and Crawford Counties, Kans.	23	7:30 p.m.	880	0	1,000	do	Farm buildings damaged; path 7 miles long.
Bourbon County, Kans	23	7:30-8 p. m.			1,000	High winds	Chief damage was in the northeasterly part of Fort Scott, mostly to roof of a packing plant.
St. Bonifacius, Minn., and vicinity.	23	11:30 p. m.	1 1		10,000	Severe thundersquall	Large ice house and number of small buildings, silos, and wires blown down; windows in greenhouses broken.
Minnesota, extreme western counties.	23-25				50,000	Thundersquall, sleet, and snow.	Moist snow and sleet that froze measured from 2 to 3 inches in thickness as it clung to wires and trees in Beardsley and Luverne, Minn., the heaviest ice formation occurring at the latter place. Unusually heavy snow delayed traffic seriously. A number of automobile accidents occurred. Many poles and wires down, trees uprooted, buildings damaged, windows blown in, and 3 automobile trucks blown over.
Fort Dodge, Iowa	24	A. m.		0	7,500	Tornado	A feed plant, stockyard, and several homes badly damaged.
Dothan, Ala., vicinity of	24			1	5,000	do	5 persons injured; property damaged.
Benton, Ark.[2]	24			2	40,000	do	Many persons injured; many homes destroyed or damaged.
Whitfield and Murray Counties, Ga.	24				10,000	Hail	Loss to truck farmers.
Fairbury, Ill	24				500	do	No details.
McLean, Livingston, Sangamon, Logan, Montgomery, Macoupin, Coles, and Monroe Counties, Ill.	24				65,600	Wind	Small orchard destroyed, property damaged, and trees uprooted.
Iowa, northern, west-central, and southern sections	24					Blizzard	In spotted areas, where 4 or 5 inches of snow fell, drifts 8 feet high blocked the highways. Primghar was completely isolated. Telegraphic communication suspended. Many stalled cars abandoned; 100 persons were stranded at Adair.
Moorhead, Minn	24					Wind and snow	Considerable damage, the greatest being to communication lines.
Lincoln, Nebr	24					Wind	A number of plate-glass and other windows broken, a garage blown over, porch blown from a house and numerous signs destroyed.

[1] Miles instead of yards.
[2] From press reports.

TABLE 4.—*Severe local storms, April 1937*—Continued

Place	Date	Time	Width of path, yards	Loss of life	Value of property destroyed	Character of storm	Remarks
Omaha, Nebr.	24				$25,000	Wind	Plate-glass windows broken; power lines down.
Pulaski, Tenn., vicinity of	24	1:30 p. m.	200	0	3,000	Tornado	3 persons injured, 2 houses demolished and several buildings unroofed.
Nebraska, eastern portion	24–25		100		20,000	Wind	Plate-glass windows broken; small buildings blown over, signs and poles down, and trees broken.
South Dakota, eastern portion	24–26			1	225,000	High winds, rain, and snow.	About 2,000 telephone poles down, most of them between Aberdeen and Sioux Falls. Train service delayed. Railway accident in which 1 person was killed on the morning of the 25th because of a blinding snowstorm, 3 miles west of DeSmet.
Atlantic City, N. J.	26					Wind and rain	Heavy seas caused considerable damage to coast property; three persons injured.
Ocean City, N. J.	26					do	Heavy seas caused considerable damage to coast property.
Allendale, S. C., and vicinity	27				2,000	Hail	Roofs and automobile tops damaged; windows broken. Hail reported to have been several inches deep. Considerable crop acreage had to be replanted.
Nemaha County, Kans.	29	5:47 p. m.	2			Heavy hail	Originated a mile west of Oneida and crossed the line into Nebraska, 6 miles north of Sabetha. Fruit seriously damaged, loss to crops; many window panes broken. Path 14 miles long.
Missouri, southwestern portion	29			2	22,000	2 tornadoes	2 persons killed during the 1 near Ash Grove. In Texas County, $22,000 property damage; 20 persons injured.
Mobile, Ala., and vicinity	30	6:30–9 p. m.				Thundersqualls	Squalls of approximately 70 miles an hour were frequent between 7:15 and 8:15 a. m., causing considerable damage to trees and shrubbery. The storm came without warning, and, while there was an apparent slackening of its intensity after 9 p. m., at Mobile, reports along the coast indicate that it continued without any cessation until about 2 a. m., May 1.

Chart I. Departure (°F.) of the Mean Temperature from the Normal, April 1937

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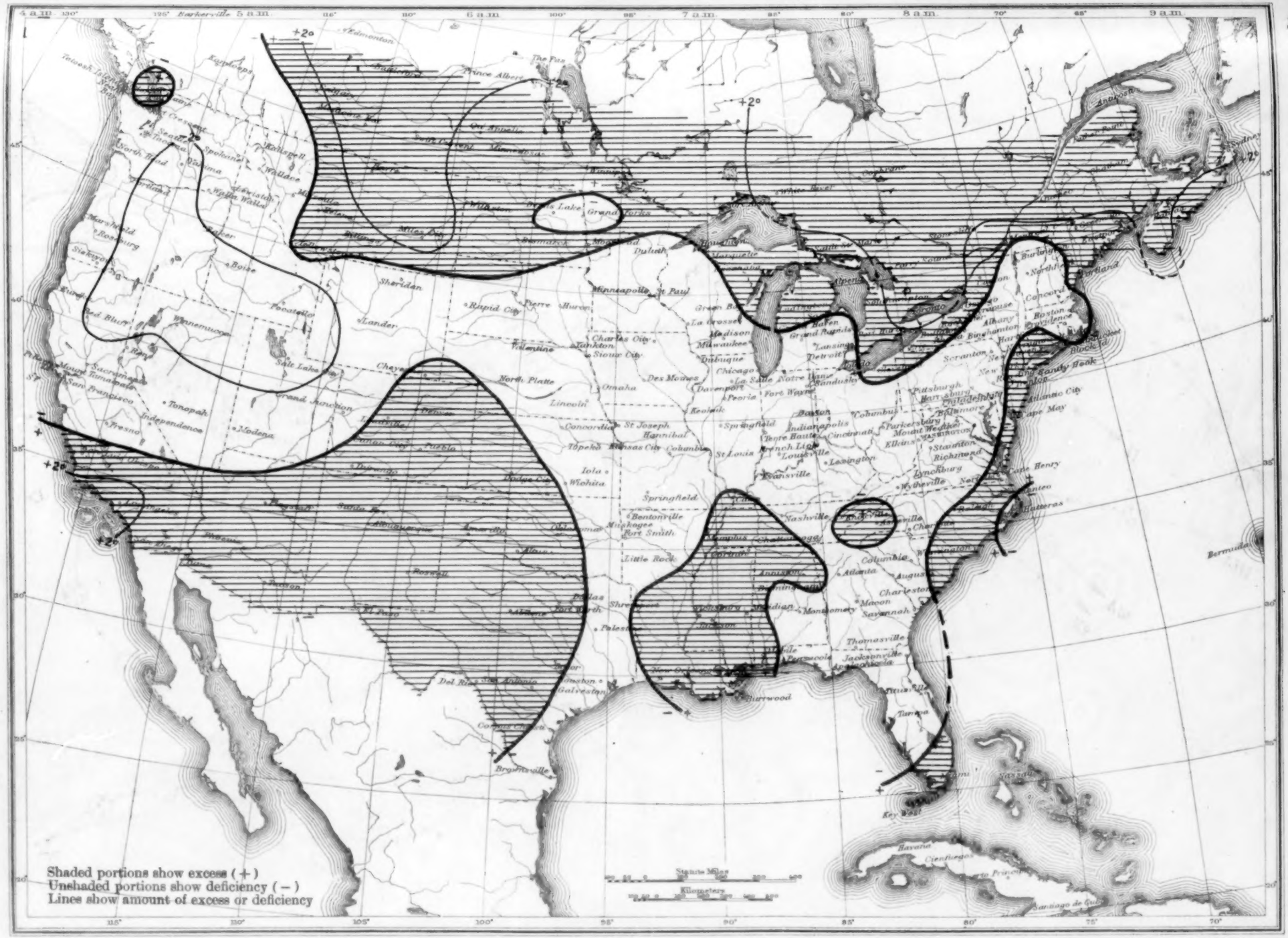
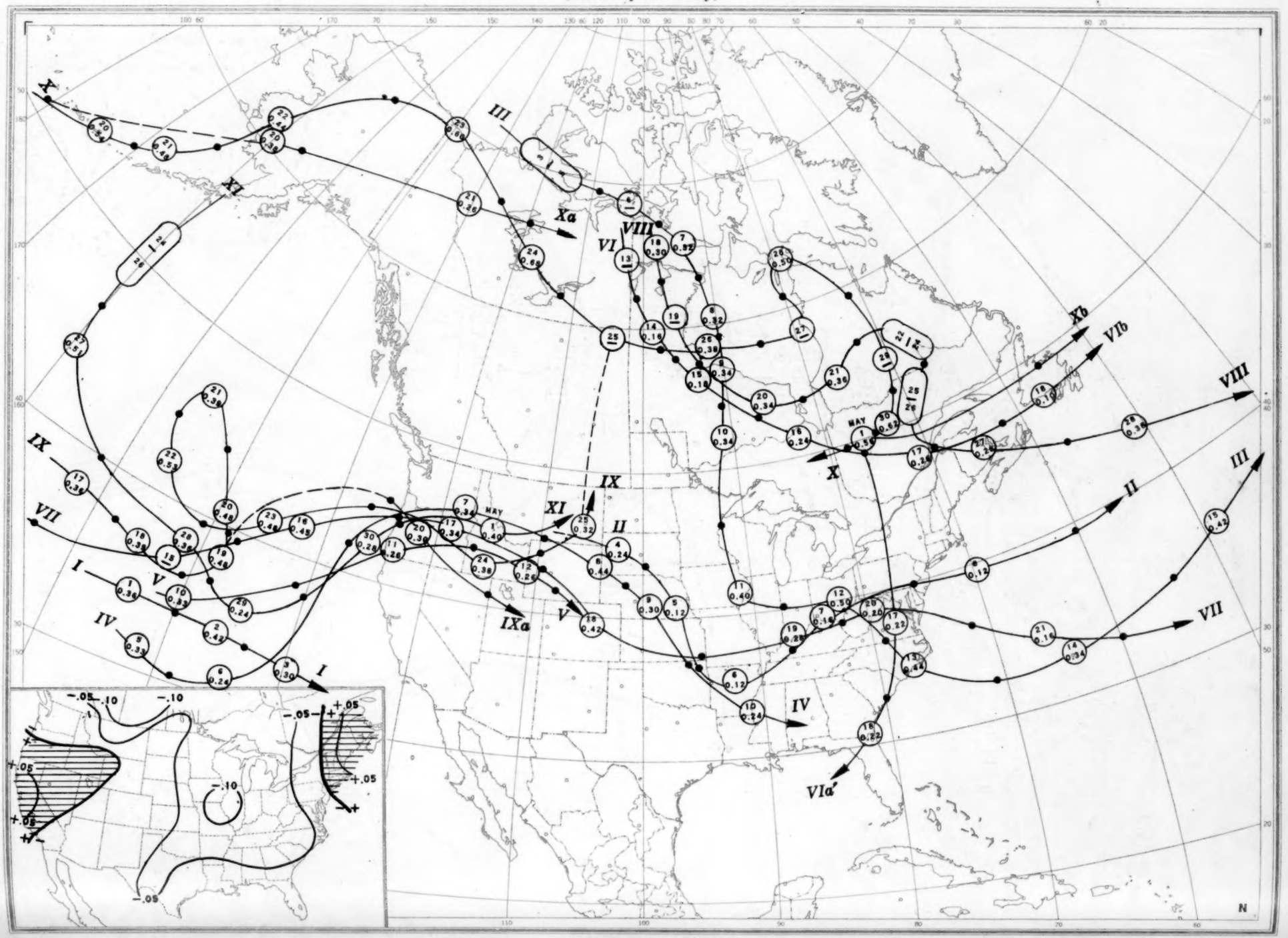

Shaded portions show excess (+)
Unshaded portions show deficiency (−)
Lines show amount of excess or deficiency
Statute Miles
Kilometers

Chart II. Tracks of Centers of Anticyclones, April 1937. (Inset) **Departure of Monthly Mean Pressure from Normal**

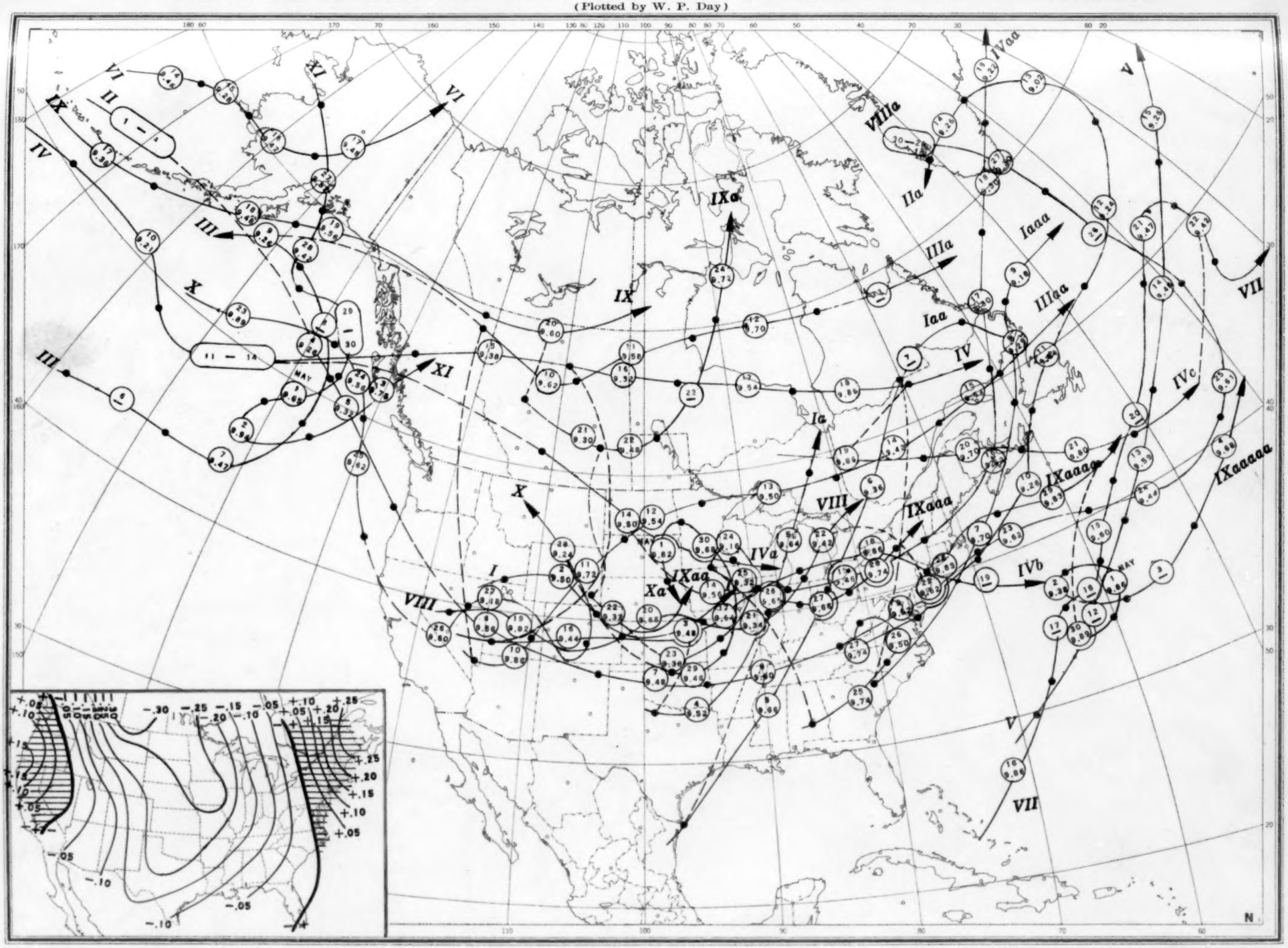
(Plotted by W. P. Day)



Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 7:30 p. m. (75th meridian time).

Circle indicates position of anticyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 7:30 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, April 1937. (Inset) **Change in Mean Pressure from Preceding Month**
(Plotted by W. P. Day)



Circle indicates position of cyclone at 7:30 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 7:30 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, April 1937

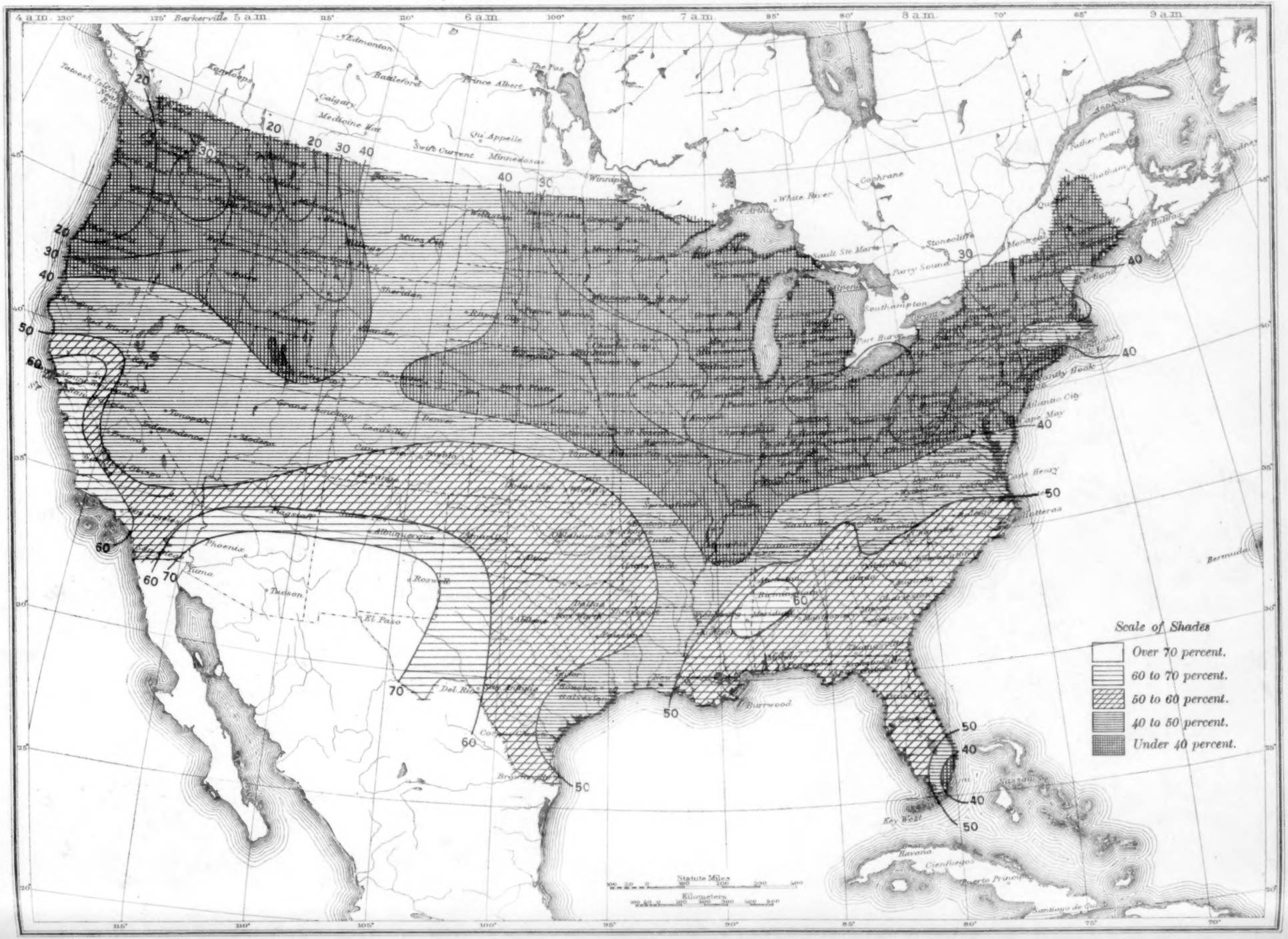


Chart V. Total Precipitation, Inches, April 1937. (Inset) Departure of Precipitation from Normal

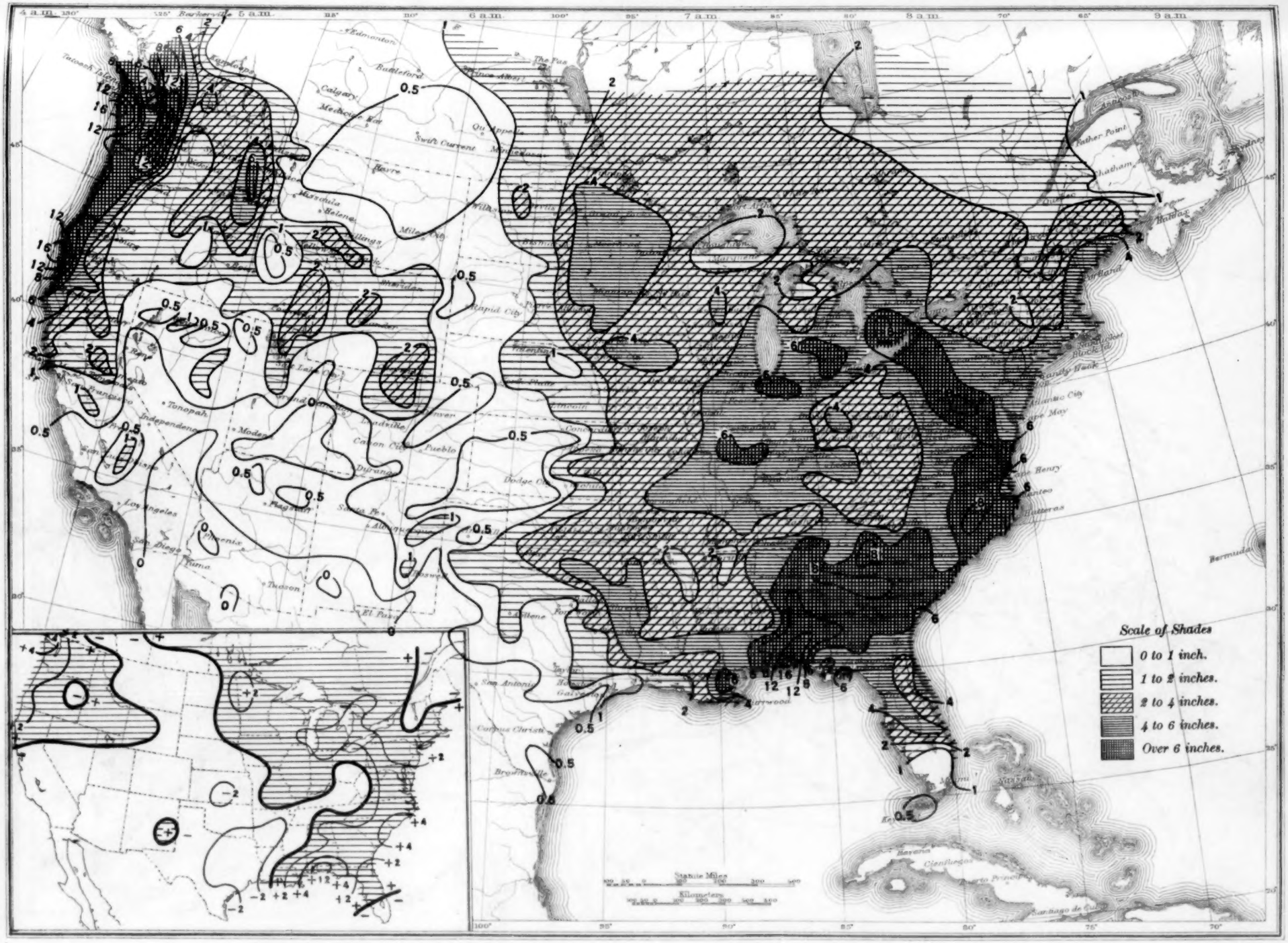


Chart VI. Isobars at Sea Level and Isotherms at Surface; Prevailing Winds, April 1937

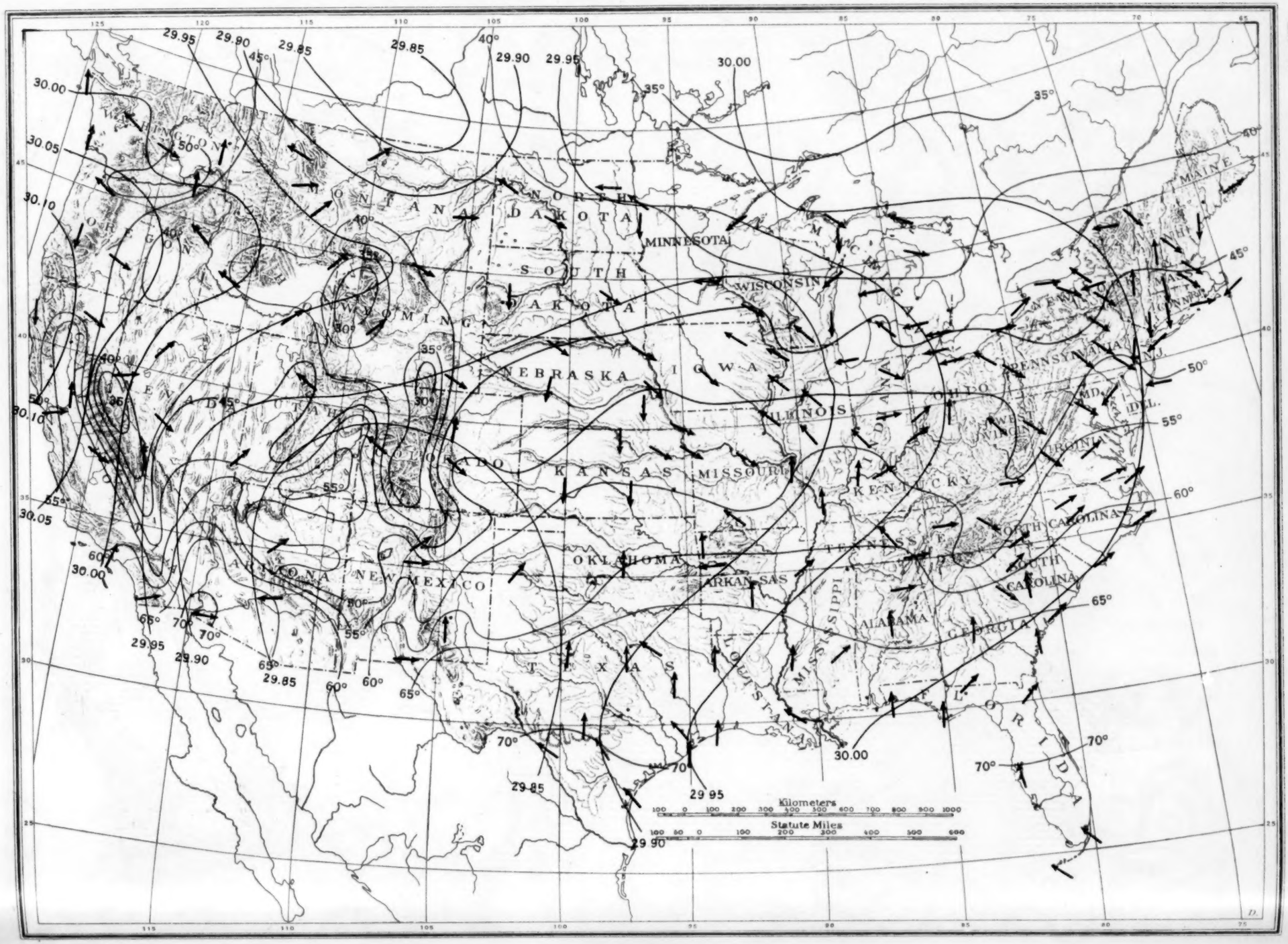


Chart VII. Wind Roses for Selected Stations, April 1937

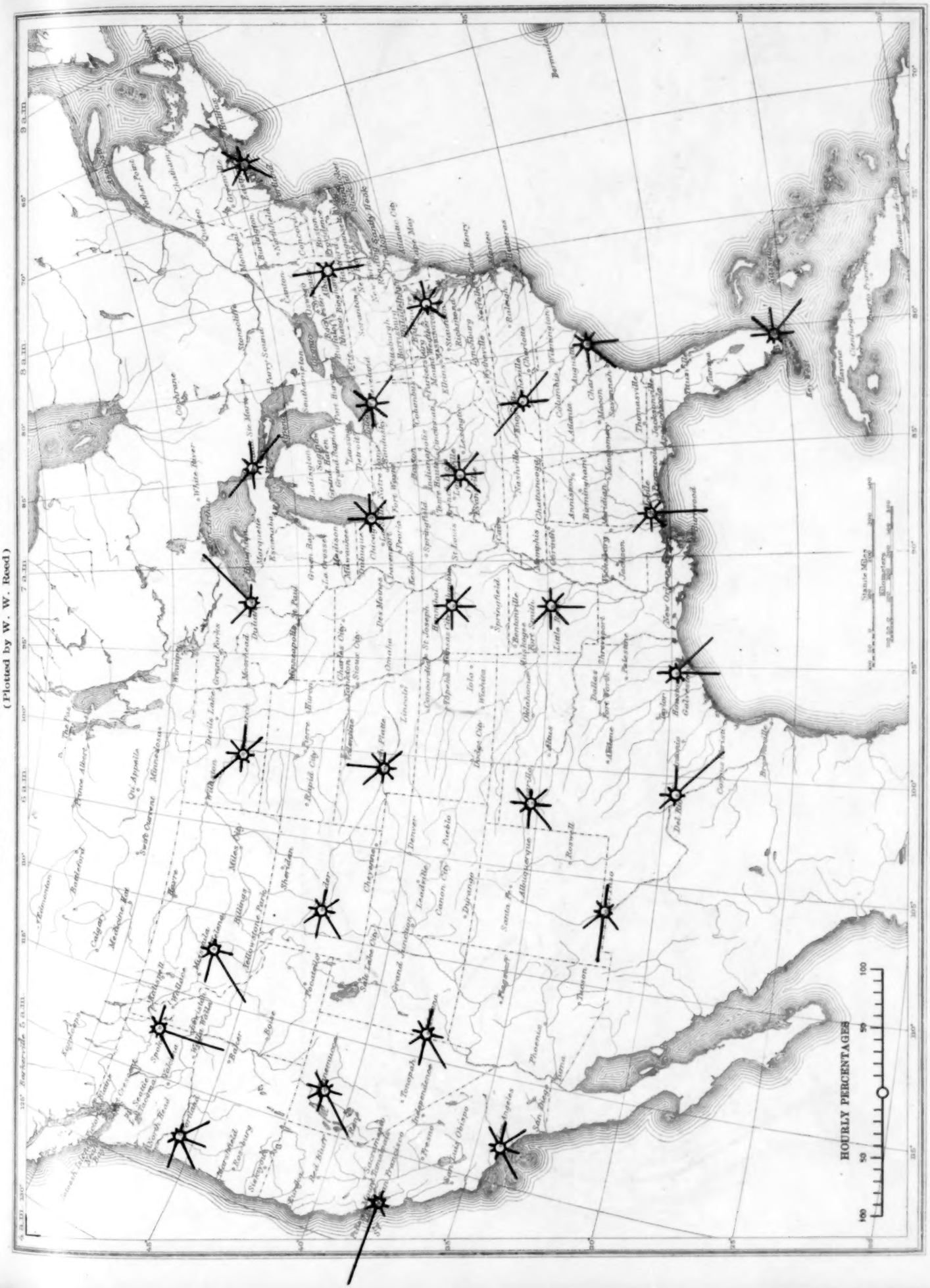


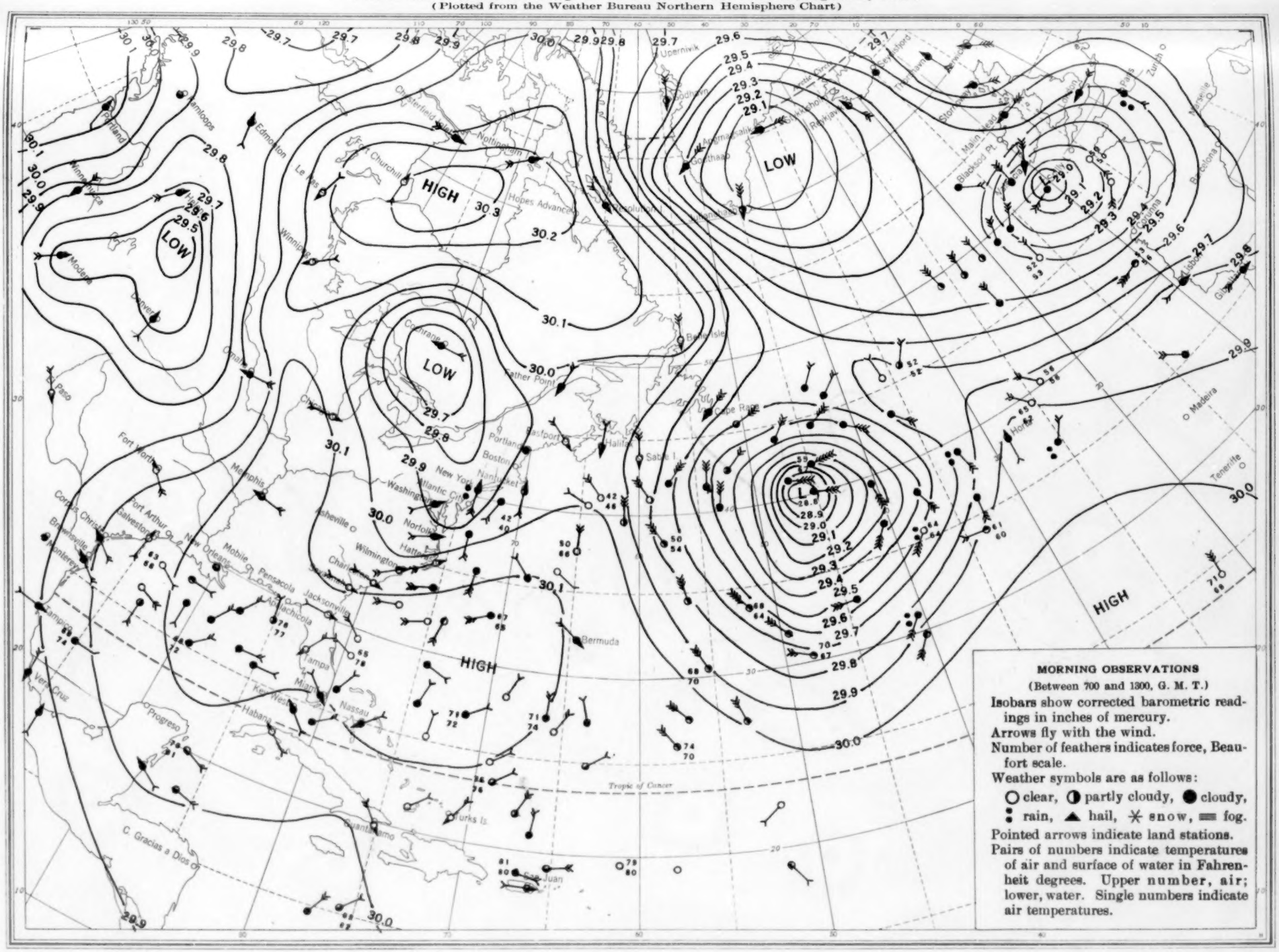
Chart VII. Wind Roses for Selected Stations, April 1937
(Plotted by W. W. Reed)

Chart VIII. Total Snowfall, Inches, April 1937

Chart IX. Weather Map of North Atlantic Ocean, April 2, 1937

Chart IX. Weather Map of North Atlantic Ocean, April 2, 1937

(Plotted from the Weather Bureau Northern Hemisphere Chart)


HIGH
LOW
HIGH
LOW
LOW
HIGH
Tropic of Cancer
MORNING OBSERVATIONS
(Between 700 and 1300, G. M. T.)
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicates force, Beaufort scale.
Weather symbols are as follows:
clear, partly cloudy, cloudy,
rain, hail, snow, fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water. Single numbers indicate air temperatures.